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Editors:

THE ANIMAL WORLD

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WITH INTRODUCTION

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AUTHOR'S PREFACE

I am especially indebted to my wife for help in the preparation of the MS. of this work.

F. W. G.

INTRODUCTION

The mystery of life in its interaction with or utilization of matter is one of the outstanding puzzles of the Universe which confronts not only every physicist and chemist, but every educated man. Biologists, who know so much about living beings, must feel the deciphering of the hidden meaning of life itself as a standing challenge. Every year, no doubt, brings them nearer to a solution, but to all appearance that solution is still far away. In that respect they are only in the predicament of the gravitational astronomer, who, though able to apply his theory to the most hidden perturbation and announce predictions which are capable of triumphant vindication, yet is ignorant, completely ignorant, of the nature of the gravitational force itself. From time to time thinkers are at work, however, and every decade the problem shows signs of becoming more soluble: hope is in the air as regards gravitation, and there is at least vivid speculation regarding life.

Meanwhile, the mass of the public are far more interested in the problems presented by living creatures than in those pertaining to astronomical physics; and the kinds of study necessary to

assimilate the researches of biologists, so long as they are not clothed in too artificial and repellent a language, is not of a recondite character, but is interesting and attractive.

The multifariousness of existence is so great, however, that the untrained observer must assuredly lose his way without a guide. A clue is necessary, one which will call attention to the points of resemblance, the similarity amid difference, the family relationship running through the animal kingdom, the chain or intermediate stages linking together the simple and the complex; a student can thus be led to appreciate the fundamental properties and powers which are common to them all, but which put on so different an appearance in different cases, exhausting almost every possibility of variation, and exceeding in actual achievement the resource of the most fertile imaginations.

Most textbooks of zoology are content to describe the different organisms in an ascending series, beginning with a single cell so simple as to be indiscriminately animal or plant or neither or both, and passing on through a definite but many-branching series of gradations till the outermost twigs of each branch are reached—ferns, shall we say, along one limb, trees and flowering plants along another, cuttlefish along another, bees yet another; while, following other lines of development, we are led to the extraordinary

wealth of animal life culminating for a time respectively in shark, lizard, eagle, man.

That series of ascending chapters is the ordinary and very necessary prelude to a study of zoology, but this little book of my friend and colleague, Professor Gamble, pursues a different course.

It assumes some knowledge of the animal kingdom as popularly treated, and proceeds to consider it not so much as a chain of development, or as groups to be subdivided and classified, but from the point of view of *function*. Its object is to trace the similarity of function running through the whole series, to emphasize the extraordinarily various modes in which these functions are performed, the diverse organs grown for their due performance, the reaction of achievement on form and of form on achievement—so that the necessity of a function seems to grow a suitable organ and the possession of the organ leads to other and higher functions—a kind of action and reaction of the utmost interest and variety. In this way the similarity of the needs of the highest and of the lowest—the likeness, we may say, of man to the Amœba—is forcibly brought out, and all the wealth of knowledge of a biologist is made available to the reader of keen aptitude but small knowledge.

For the thoughtful and philosophically-minded student at the present day, such a book is most

timely and helpful. In it the salient facts are dissected out from an overwhelming mass of material, and attention concentrated on a few functions of overwhelming importance and on the variety of ways in which they are performed.

Movement or locomotion is one such function, the influence of which on the life of the race can hardly be exaggerated. Movement at some period of life is essential to both animals and plants, and the power entails the individual in difficulties and risks which demand either intelligence or else so great profusion that dangers may be ignored. Usually it is the young who are most active. Occasionally it is the reproductive adult, as in insects. Sometimes the power of locomotion is confined to the seeds alone, as in many plants. It may be reduced to a creep or crawl, sometimes it is a parasitic or otherwise assisted habit, but if the power of locomotion did not exist the species could not spread. The power has in many cases developed far beyond obvious necessity, and has become a source of joy, as in the bird, or a great interest in life, as in man.

Breathing and feeding, again, including the capture of food, are essential functions which have evolved organs of great variety and interest. The colours and the senses of animals are closely connected either with capture or with escaping capture. The association in flocks for mutual

help and support, the care of the young, and the deeply interesting laws of Heredity and Variation, are facts which run more or less through the whole realm of life, nor are they limited to the animal kingdom alone. All these topics are dealt with by Professor Gamble, they are all topics which are very much alive at the present day, and the information that he gives is the kind of information which, in a general way, every educated person would wish to possess.

That, I take it, is partly the object of the series of books of which this forms one, and I am glad to have the opportunity of commending the series to that increasing number of readers who are hungry for trustworthy and assimilable information.

One of the most striking phenomena which have recently come to light is the deadly effect of too long continued isolation. Cells can multiply by fission or mere subdivision for a certain period, but there comes a time when unless they are rejuvenated by union with another cell, their power becomes feeble and the whole colony decays and dies. Contact with another or supplemental cell, sometimes resulting in actual combination, renews the vigour of both, and the process of fission can afterwards go on for much longer. The light which this throws on the origin and deep-seated necessity of sex is manifest; and the process of combination or fusion of individuals

who had developed separately is curiously reminiscent of the inverse process imagined by Plato in the *Symposium* as an historic account of this strange longing. And probably Plato intended something quite serious by this legend; though, as if to safeguard himself from too literal an interpretation of his parable, he puts it into the mouth of Aristophanes in order that it might be treated as a joke by those who had not ears to hear; thus safeguarding his position somewhat after the same fashion as Virgil safeguarded his vision of the underworld—his doctrine of pre-existence and reincarnation—from the scoffer, by allowing Æneas and the Sibyl to issue into upper air again through the ivory gate instead of through the gate of horn.

It is through the gate of horn, however, that biologists lead us; and, in the light of our extending and growing knowledge of Physics and Chemistry at the present day, there can hardly be a more fascinating study than that of the fundamental elements of life and the action of material surroundings—whether naturally or artificially supplied—on the life-history and development of the simpler and more easily studied modes in which Life, whatever may be its intrinsic nature, incarnates itself upon the planet.

Oliver Lodge.

THE ANIMAL WORLD

CHAPTER I

THE STRUCTURE AND CLASSIFICATION OF ANIMALS

In order to study and understand animal life it is necessary to have a few clearly defined conceptions of the nature and range of animal structure and of the genealogical trees on which animal pedigrees are founded. To many people this part of the subject is less interesting than the study of habits and of life-histories, but without a training in comparative structure and classification, observations and experiments are of little help. We must know what is the material we are dealing with before we can understand its amazingly varied activities and adaptations. We have, in fact, to detach the animal from the environment before we can appreciate its life. But to appreciate animal life fully we have to investigate both its activities and its structure.

At the base of the animal kingdom is the large and important division, the Protozoa. The Pro-

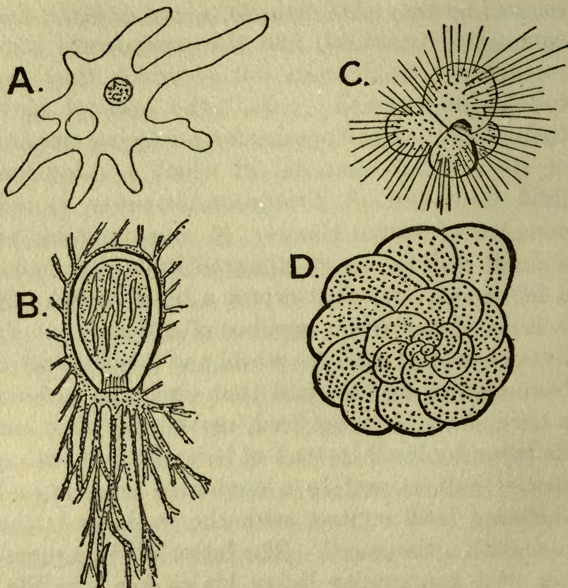
tozoa, or "Animalcules" of older writers, are creatures of the simplest type known, with the exception of the bacteria, about the nature of which there is some doubt. Excluding microbes, however, from the scope of this book, Protozoa take the lowest place. They are not to be considered as primordial in the sense of being the first created animals; as to that we have no evidence; but they undoubtedly furnish us with the simplest self-contained unit of animal structure, and their remains have been found in the records of the rocks as far back as any indication of life. Indeed the flinty or limy skeletons of these animals help to build up the rocks. Many sands, limestones and sandstones of certain mountain ranges are largely made up of their remains, whilst the pyramids of Egypt are vast piles of a Protozoon about the size of one's finger nail. Protozoa abound in the sea and in fresh water in all latitudes. They occur in soil to an unknown extent and in uninvestigated variety; and they occasion some of the most serious diseases from which man and beast can suffer. Sleeping-sickness and malaria are two of the most notorious. On these several accounts the study of Protozoa has been greatly pursued of late years.

In order to appreciate the structure of these animals, we must refer for a moment to the organized nature of higher animal tissues. These

tissues, be they skin, muscle, nerve or bone, are composite structures, and the component, microscopically small units out of which they are formed are termed "cells," the cells of each tissue being bound together by a varying amount of structureless material in which a colourless fluid circulates. A Protozoon, however, is not compact of varied tissues. It is comparable to a single cell, to one of the multitude that make a nerve-centre or that crowd a blood-vessel. It is isolated and not a member of cell-society. It lives in contact with the world and is not shielded from change by the fluid that circulates around a tissue-cell. It must feed, move, and work out its being by itself instead of being bathed with a special pap, stirred to a conjoined exercise and sheltered from contact with the world as is the case with a tissue-cell. The latter is like a member of a community living his or her own life, but doing one thing, performing one office for the body politic out of which livelihood is gained. The Protozoon is like a Robinson Crusoe, who has to save his life by his own efforts without any chance of Man Friday giving him aid.

This isolation of the Protozoon, while exposing it to many dangers, has the advantage of giving room for showing inborn capacity for adaptation. A tissue-cell, like a factory hand, has to do one office, and to keep itself well enough to do that,

A. C.



B. D.

Fig. 1. — Group of simple Protozoa (highly magnified).

A. *Amœba* (× 200): the dark spot is the "nucleus" or governing centre of the organism, the clear space is the "contractile vacuole," by which effete matters and carbon dioxide are discharged.

B. *Gromia:* one of the common shore Foraminifera (× 15), showing the protoplasm streaming out of the test or shell and capturing diatoms.

C. *Globigerina:* a pelagic foraminiferan (× 20), showing the chambered shell and the spines with which it is covered. The shells or tests of this animal form an important part of the deep-sea deposits into which they fall upon the death or upon the sporulation of the animal.

D. *Rotalina:* this is another important element in globigerina ooze, and is also found in many limestones (× 6).

but a Protozoon is the servant of none. Its energies are devoted to self-maintenance and the acquisition of that place in nature (whether in water, on land, or as a parasite in some animal) in which its inborn faculties may find their scope. The result of this plasticity is that some remain simple, inert, shapeless lumps of moving jelly; others according to their kind develop temporary motile, hairlike tentacles singly or in series by which they row themselves through water or some internal fluid of their host; others evolve one of several means of buoying themselves in the ocean or in fresh water, as by growing radiating processes and secreting bubbles of jelly which they fill with gas. Some coat their bodies with a protective envelope in which they imbed foreign matter for greater comfort; some deposit lime in shells of a thousand different forms constant in each "species"; others construct needles and shells of flint in a variety of graceful and often complex patterns. The sea is often full of such exquisite and imperishable coronals. A protozoon is therefore not necessarily simple. It has simple tools—a mere speck of protoplasm with a firmer but minuter speck or two at its centre. Yet with these it may evolve imperishable workmanship of the most exquisite form, or it may remain as it was born, a shapeless, unprotected and changeable being. The fate

of each is decided at birth and no effort or change of environment can alter it. The tools are almost the same for each. The work of one will last longer than the hills it serves to form, while that of the other leaves no mark.

This individualistic life is, however, a short one. How long a tissue-cell may live we scarcely know. A nerve-cell may last a lifetime. It remains single. But the other cells, bone-cell, skin-cell, and so on, are short-lived. Some perish and leave no descendants, but the majority merge themselves in daughter-cells after a few hours or days of individual life. They do not die, but divide and become twain. In some disorganized tissue-cells so great is this tendency for fission that their daughters and succeeding generations break the bonds of their confining walls and penetrate into surrounding tissues, giving rise to some form of that dread malady, cancer. Now among Protozoa this multiplying tendency is equally general. The body, cased or free, divides and becomes merged in its offspring, and these may at once separate and set about their welfare or may live together in a common envelope if the conditions are favourable. In this way we receive a first hint of those animal colonies that become such striking features in the corals, the sea-mats (Fig. 17) and the sea-fir. The Protozoon, barring accidents, would seem to be im-

mortal. It loses itself in order to find life in its descendants. A single monad (a minute speck

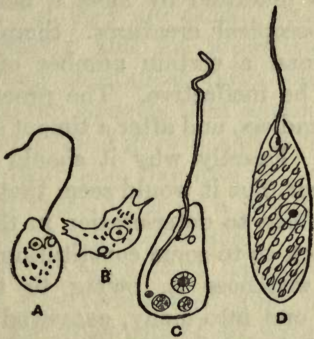


Fig. 2.—Flagellate Protozoa (highly magnified).

A, B. Springing Monads in the flagellated and amœboid states (× 900). These monads are extremely common in decaying material, in foul water, also in the bodies of earthworms and in soil. The body is provided with one or more whip-like processes, by which springing movements are executed, but at certain times the flagella may be withdrawn and replaced by pseudopodia as in B.

C. A flagellate (*Copromonas*) from the intestine of the Frog to show the structure (× 900). On one side of the flagellum is seen the mouth leading into a narrow tube down which food has passed. The nucleus is also shown (with black centre).

D. *Euglena:* a green flagellate (× 300), very common in fresh water. This animal is provided with green chromatophores (starch-formers), and behaves in many ways like a plant. The nucleus is seen about the middle of the body.

with one or more elastic motile cilia) will in this way multiply to the million in a few hours, in an infusion of hay (Fig. 2).

But as though the hunger for life were not enough, there is still another mode of perpetuation that is practised by most if not by all of these microscopical creatures. Simple division carried beyond a certain number of cleavages appears to be ineffective. The process though long is not endless, and after a time it slows down and ceases. Exactly why it should do this is not very clear, but it would seem that the slackening is not due to deterioration in the environment so much as to some constitutional weakening. Any weakness is, owing to the simple cleavage of one into many, conveyed to the descendants and there seems to be no rectifying property. It has been found that if such a strain or culture, the members of which are derived from a single Protozoon by repeated fission, is isolated, it gradually dwindles and dies. If, however, it is allowed access to another culture of exactly similar appearance, it undergoes a renewal of this dividing property, and after an interval once more populates the water.

This "rejuvenescence," as it is called, is bound up with a process known as conjugation, which occurs when access is afforded between the two strains or cultures of a Protozoon. Sometimes, as was said, the two may be exactly alike so far as our present tests can go. Sometimes there is a marked difference (Fig. 3, c) between the in-

dividuals that conjugate, a difference of size, complexity and movement. In either case the "gametes," as they are called, fuse temporarily or permanently and an interchange of their several living substances takes place. In the former case the gametes then separate and enter on a fresh period of growth and division; in the latter, the two bodies fuse into one, and from this immolation there proceeds a new generation of descendants by repeated fission.

The study of conjugation has revealed a complexity of occurrences that were formerly unsuspected and that cannot be stated in such a brief sketch as this. What is of chief importance is the fact that associated with this study is the discovery of sex. It is now known that even the Protozoa are at some period of their life male or female; and that what "rejuvenates" a colony or stock exhausted by mere duplication is the impulse received by members of another sex. Not in all Protozoa, nor in these at all times, is the male as definite and as distinct from the female as it is in those figured. But the distinction is there, and the longer these Protozoa are studied the more clearly is seen this cleavage into, and union between, the sexes.

This fact of sex at once invalidates our comparison of a Protozoa with a tissue-cell. Up to a point the simile holds. The animalcule is a

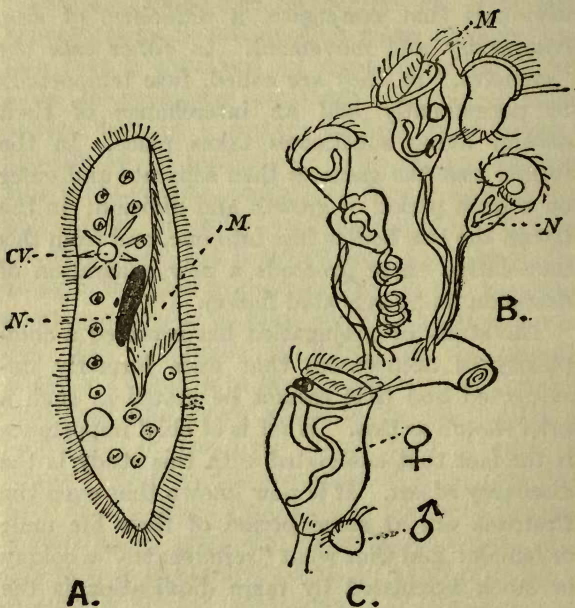


Fig. 3.—Ciliated Protozoa (Infusoria).

A. *Paramecium*, the slipper-animalcule (× 225). This abundant infusorian occurs in fresh and salt water, and also in cultures produced by steeping hay in water. The body is slipper-shaped, the cavity of the slipper being the mouth-cavity. This cavity leads into the body-substance as shown, and the food (which consists of bacteria) circulates clock-wise. The large black oval spot is the body-nucleus, the minute spot close to it being the germ-nucleus. In speaking of Protozoa as single cells or units of living matter, it is important to bear in mind that they frequently, if not always, contain two perfectly different nuclei. The star-shaped structure is the contractile vacuole.

unit as the cell is the unit of life. But it is something more. It is not merely a self-sufficing and self-duplicating unit. In the course of one of these incarnations the initial Protozoon becomes a male cell or a female cell incapable of further life if not given access to its supplementing mate, casting out much substance to effect and consummate that access and rejoicing, if we may so say, to found a race. A Protozoon is, therefore, a cycle of events in part of individual, in part of racial incidents. Each incidental individual is not a single cell but a double cell, a twin star, and is therefore in virtue of that essential duplicity incomparable with any one of the constellations of cells that we call a higher organism. The whole mass of dividing individuals represents the body of that organism, whilst the male and female individuals of this conjugating period represent the germ-cells of the higher organisms.

B. A group of Vorticella (× 100). These Protozoa abundantly found on weeds and perched on small animals, occur both in fresh and salt water. Each consists of a body and stalk. The body is surrounded by a zone of cilia, by means of which bacteria are inhaled and passed into the mouth (M). The nucleus (body-nucleus) is a coiled structure, and the germ-nucleus is extremely small.

C. The ordinary stalked form of *Vorticella*, attached to which is a minute free-swimming form produced by repeated sub-division of a stalked individual. The first behaves as a female (♀), the second as a male (♂). In conjugation the male is absorbed into the body of the female.

METAZOA.—In higher animals ("Metazoa") the body is no longer a single cell, but is composed of a vast colony of cells comparable to all the myriads of cells that arise by fission from a single Protozoon, and the comparison is made closer by the fact that each multicellular animal arises by subdivision of a single cell, the ovum or egg-cell. Some factors not present in Protozoa constrain the fission-products of this ovum and make them cohere. The presence of calcium is one of these factors; others, however, are present, for the body is not a mere heap of similar cells. It is composed of tissues; it is given a definite form; it grows by degrees to a definite size; it may pass through a variety of experiences and phases before reaching adolescence, and then may abandon the individualistic tendencies that it has so far followed, in order to adopt means for producing and protecting its family.

Unlike those of many plants, the form, structure and life-histories of animals are determined largely by innate factors and depend to a far slighter extent upon environment. In a similar way the relationships of animals and their places in classification are determined largely by hidden facts of structure rather than by the more familiar and external features. In fact, it is the more remote and valueless features of animal structure that are the clearest signs of affinity, for being

of little use they have persisted unchanged whilst more functional organs have become adapted to various ends. The silent letters in many words, such as the "b" in doubt, the "g" in reign; the buttons on our coat-sleeves; the ears on our

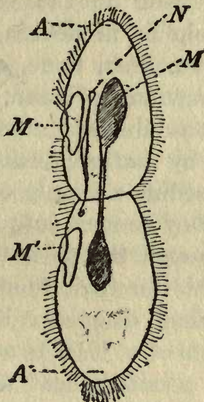


Fig. 4.—Illustrating the mode of division of a Protozoon (*Paramecium*). M, M′, the new mouths; A, anterior end of one daughter-cell ; A′, posterior end of the other. M and N are the great and small nuclei or governing centres respectively. (After Hickson.)

faces, are such survivals, which form valuable evidence of relationship between words in different languages, costumes in different centuries, and animals of different kinds, exactly in proportion to their uselessness for any purpose.

In order to appreciate animals, therefore, it is

necessary to go below the surface, and to use language which may be unfamiliar but has the inestimable advantage of definiteness. Terms such as reptile, insect, worm, fish are used in the vaguest manner and have no scientific meaning unless defined. Nor do the vernacular words for structure help us in defining the genealogy of animals; nerve, flesh, bone, skin are capable of many meanings and of none; a more precise nomenclature is an absolute necessity.

Animals are by nature flexible, and usually motile beings needing a supply of solid food (pp. 72–74), which they convert into a fluid form and then diffuse through the tissues. This primary fact is responsible for their fundamental, hollow nature. An animal, disguise it how we may, is a tube. It consists of at least two layers: an outer protective and sensitive coat and an inner digestive and also sensitive one. One or two kinds, it is true, consist of a single coat of cells, but it is not at all certain whether these extremely rare creatures are as simple as they appear. They may turn out to be simplified from some more highly organized and double-layered family, which has become arrested at a juvenile stage of its life-history. In all other cases this one-layered stage becomes converted into a double-layered tube, if not indeed into still more highly organized structures. This two-layered condi-

tion is the limit for a few fresh-water and a vast number of marine animals, and is expressed by the term *Cœlenterate.* All hydroid zoophytes, jelly-fish, corals, sea-fans and sea-pens are *Cœlenterates*, and consist essentially of a tube with two coats: an outer one, the *ectoderm*, and an inner one, the *endoderm.* The two coats are not loosely fitting, but are bound to each other by a greater or lesser amount of soft cement. In Zoophytes, the amount is very small, but in jelly-fish and corals the soft intermediate jelly is bulky and confers the thick, soft character upon these animals. Into it both ectoderm and endoderm bud off cells, and these play the middle-man between the two primary layers as well as having special functions of their own. In this way increase in bulk is accomplished without loss of touch with the vitalizing and nourishing water. This middle, usually soft tissue, is known as *mesenchyme.*

Cœlenterates.— We may now briefly describe the modifications of structure found within this great phylum, the Cœlenterates. The body consists of a tube closed at its lower end. The open upper end is the mouth, which is usually surrounded by a number of tentacles or hollow outgrowths of the tubular wall. Currents of water play up and down the tentacles and body cavity or "Cœlenteron," carrying food and oxy-

gen to the mesenchyme and so to the ectoderm. Around the mouth specially nervous processes of the ectoderm-cells serve as a rudimentary nervous system, whilst longitudinal outgrowths of both ecto- and endoderm act as muscles for elongating or shortening the body and tentacles. There are, however, no blood-vessels, no kidneys for removing effete matters, and no distinct muscles (Fig. 5).

The body has usually and to a high degree the power of budding so as to form colonies. The buds may resemble the parent and remain in connection with its tissues by strings of mesenchyme, or they may take a form very different from the parent-stock and separate completely. Such detached buds are jelly-fish. The parent-stocks of practically all jelly-fish are fixed. The free-buds are actively pulsating medusæ without any trace of skeleton, but provided with an enhanced power of movement, a more elaborate nervous system, and with organs for the perception of light and the maintenance of balance. Many Cœlenterates, however, have no free medusæ. The sea-anemones, corals, precious corals, sea-fans and sea-pens have only fixed, not free-swimming polypes.

These flower-like animals are incessantly inhaling water down their inverted throats and exhaling it through one or two special grooves

placed at one or both angles of the slit-like opening. Their length of life is considerable; a

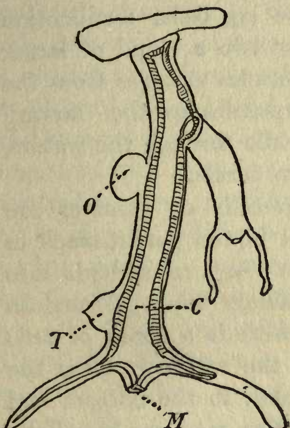


Fig. 5.

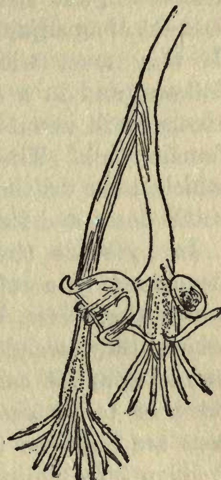


Fig. 6.

Fig. 5.—*Hydra*, the common fresh-water polyp, showing a bud on one side and an ovary (O) and testis (T) on the other. The figure is taken from a longitudinal section through the body in order to show the simple structure. The cavity (C) opens to the exterior only through the mouth (M), and has a double wall, the inner layer being endoderm (inner skin), and the outer one, ectoderm.

Hydra is abundant in fresh water all over the world. (× 8).

Fig. 6.—*Bougainvillea ramosa*, a marine hydroid, budding off medusæ. (× 10.) (After Allmann.)

sea-anemone lives for fifty years, a coral for twenty-five. From time to time they emit with

the exhalent current a white cloud of fine particles which are the male germ-cells formed from the endoderm, and these are carried by the inhalent current of an adjoining individual into its interior. If they meet with ripe egg-cells, fertilization follows, and in a day or two a cloud of larger though still minute corpuscles emerges from the female stock. These corpuscles are the "larvæ" which, after drifting a while through the waters, settle down and form new corals.

In hydroids the germ-cells or gametes are developed, as a rule, not in the parent-stock in which they arise, but in the medusa-buds into which they wander. Hence when a medusa swims away, it carries with it a stock of cells destined to be cast on the waters. After the eggs are fertilized they sink to the bottom and develop into hydroids. The medusa, for all its organization, is but a sower, a disseminator.

ACŒLOMATA, PLANARIANS, ROTIFERS. — The next stage of animal organization is effected by the growing independence of the tissue we have called mesenchyme.

In Cœlenterates the mesenchyme is merely a collection of cells detached from both the inner and outer layer of the body and performing subordinate functions. In the next stage of evolution these cells form an independent tissue, not arising directly from the body-wall but

originating early in life. In order to accommodate this tissue, the space between the inner or gut-wall and the outer wall or integument is increased. The result is an organism which has sufficient elasticity to fit it for creeping. With this deep-seated change of structure there goes a remarkable change of habit and symmetry; in place of the old fixed or floating habit and radial symmetry there is now found a freely moving organism with right and left sides, and a definite ventral surface on which these animals creep: a "head-end" with eyes and brain, and an upper surface variously coloured and modified. These are the first creeping things, and include a wide range of forms for which no convenient name is available. Flat-worms; Nemertines, or sea-worms; Rotifers, or wheel-animalcules, are the most useful for the three chief divisions. The characteristic mark of these animals is their unsegmented triple-layered body. As a rule, the mesenchyme completely fills the space in which it lies, and its cells circulate the food, perform the creeping movements, expel the waste nitrogenous products of life, and provide the germ-cells by which the race is maintained. The outer layer or ectoderm is usually soft, and only in Rotifers does it build up an investment which protects its possessor against drought and attack. Its most important property is to furnish the

nervous system, which consists of a scattered mass of ganglia lying upon the ventral body-wall, usually concentrated or thickened in the head-region and down each side of the mid-ventral line. It is interesting to note that the power of sustained movement in a definite direction which is here attained for the first time in our survey, is associated with the higher development of a nervous system and of sense-organs by which light may be perceived.

Flat-worms, or Planarians, are commonly found in the sea and in fresh water, creeping like a living film over the surface of stone and shell; in tropical and warm temperate countries, land planarians occur under stones, amongst earth and under bark, but in cold temperate regions they are very rare. As is the case with so many groups of animals, that of the Flat-worms is largely addicted to parasitism. Its free-living members are carnivorous, and it is but a short step from the habit of eating flesh to the adoption of a living host for shelter and food. This step has been taken by the "flukes" and tape-worms. In its more extreme forms the influence of parasitism is profound and leads to far-reaching modification of structure and of life-history: the structure of the individual being sacrificed in order to ensure the continuation of the race.

THE CŒLOMATA.—All other animals are characterized by a hidden common bond, however diverse their appearance and general anatomy may be. We have spoken of the middle tissue or mesenchyme which plays sustentative, nutritive and motor parts in the economy of the Cœlenterates and Flat-worms. In all the higher animals (with the exception of one or two probably degenerate groups) there is formed in addition to the mesenchyme, a definite hollow middle tissue which dominates the form and structure of the body, and ultimately replaces some of the mesenchyme by a more efficient system of depuratory and reproductive organs. This hollow tissue is the "Cœlom." It may exist side by side with the mesenchyme or may displace it altogether. In its more primitive form the cœlom is a hollow pouch which grows out from the food-tube at an early period of life and gives rise to the muscles, kidneys and germ-glands. Usually it also forms a space between the body-wall and the alimentary canal by which the nourishment of the body is effected. The influence of the cœlom is most clearly seen in the form of the body. It appears to decide more than any other tissue the simplicity or segmentation of external form. In the annelids, or segmented worms (of which the earthworm is a familiar example), the cœlom is chambered and each chamber has its

outlet to the exterior. In the Arthropods (crustacea, insects, millipedes, spiders and mites) the repetition of parts or segments is also clearly seen, and is due to a large extent to the presence and subdivision of this middle tissue. In the vertebrate animals the cœlom and its products are of the greatest importance, for they give rise to the vertebræ and the muscles, and in so doing mould the shape of the fish, amphibian, reptile, bird and mammal. The simplicity of unsegmented animals is also an outcome of the undivided nature of this organ. The lamp-shells, the Polyzoa (such as the sea-mat) and the vast phylum of Mollusca are such unsegmented creatures, all of which owe their want of subdivision to their compact, undivided cœlom. Perhaps the clearest example of the moulding influence of this somewhat mysterious structure is to be seen in the Echinoderms (the star-fish, sea-urchins and sea-lilies). These animals have a radiate structure as symmetrical as that of a coral. They have no head, no brain, and consist of arms united to a disc. This star-like symmetry is entirely due to the activity of the cœlom. In early life a star-fish has no stellate appearance. It is a right- and left-sided creature, a bilaterally symmetrical one, usually bearing elegant tentacles by which it swims through the water. Before it is many days old, however, a cœlomic

pouch grows out of its throat, and after subdividing, proceeds to form a small radiate, five-lobed mass on the left side of the food-tube. This stellate internal body is the beginning of the future star-fish, the entire development of which is governed by the form of this cœlom (Fig. 36, p. 250).

Summary.—From what has been said in the foregoing paragraphs, it is clear that the classification and structure of animals depends largely upon hidden and unfamiliar factors, and that the external and easily accessible characters of animals are the result of profound changes. We may look upon the first animals or Protozoa as single cells, the division of which gives rise either to similar cells or to "gametes" which are usually either male or female. Higher animals keep their cells together in one body, which in the simplest form is a tube opening at one end and composed of two layers, the ectoderm for protection, sensation and prehension, the endoderm for digestion. The germ-cells are usually retained in the parent-body, but may be discharged in a sort of raft or medusa. Between these two layers is a jelly; and the evolution of this jelly and its cells is one of the chief factors leading to the development of higher animal forms. In the Cœlenterates the jelly and its contained cells has no independence. It arises from the two

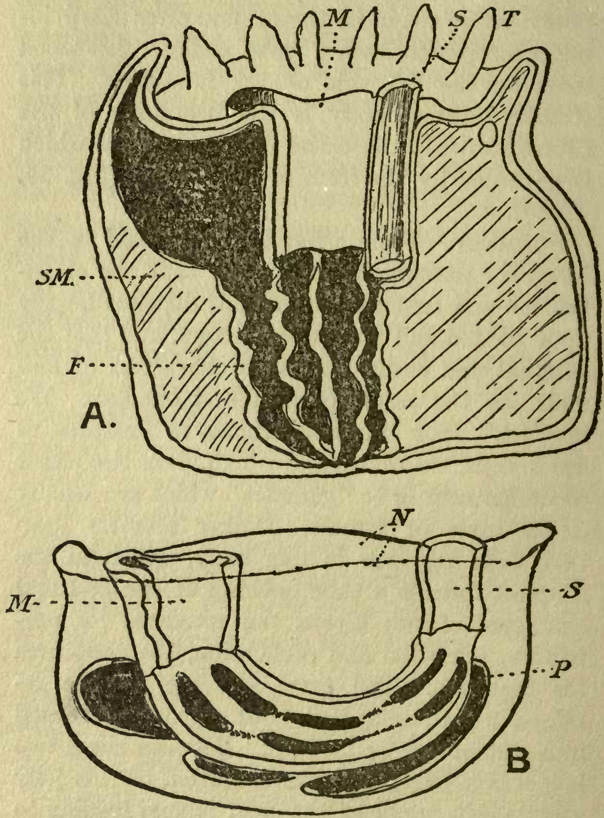


Fig. 7.—To show the cœlom and organs derived from it.

A. A diagram of a sea-anemone cut longitudinally. The mouth-tube (M), or gullet, is drawn out at its angles into two grooves or sulci (S). These grooves create an

primary layers; but in the Flat-worms it arises so early in life as to attain independence long before birth. This middle layer is called mesenchyme, and the reason for its development lies in the need for active movement. This implies better circulation of food and removal of waste matters, all of which are in turn the outcome of freer life and sustained locomotion. In their way these animals, the unsegmented worms, have learned to walk. Their brain and sense-organs are developed, and the foundations of the conquest of the earth and air are laid. At this stage these animals consist of three layers: a sensitive outer layer, a digestive, inner one, and between these a sustaining, contracting, nourishing and cleansing tissue—the mesenchyme. But just as this mesenchyme has supplanted a less

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outward-going current by reason of their cilia. The gut proper is pleated, the pleats themselves (SM) being shown on edge by the wavy lines F, and the (black) spaces between the pleats form the cœlom.

The thickened edges of the pleats are digestive filaments, and the pleats are the "septa." The digestive cavity is enormously increased by this outfolding.

At their lower ends the filaments bear ova or sperm-cells.

B. Diagram showing the supposed mode of transition from A to Fig. 8. This diagram is based upon the development of primitive Cœlomate animals (e. g. *Peripatus* and Echinoderms), which show that the primitive mouth of the early larva becomes converted into the two openings of the food-tube; and that the pleatings or folds of the primitive gut become separated off early in life to form the cœlom (P).

The nervous system is now rising up as a fold, enclosing both ends of the food-tube.

efficient jelly, so it, in turn, is replaced more or less completely by another dependency of the two great primitive layers, and in all remaining animals the tissues that lie between the skin and the alimentary canal are compounded largely out of this new "Cœlom," the blood-vessels being, perhaps, the only exception. Its advent signalizes a further advance, and the form it assumes determines that of the body. If the cœlom is undivided, so is the body: if it is segmented, the body becomes worm-like, caterpillar-like, fish-like: if it is lobed, the body becomes stellate. In this way we get the unsegmented Mollusca, Polyzoa, and Brachiopods; the segmented worms, Arthropods and Vertebrates; and the radiate Echinoderms. The following table summarizes this chapter:—

Classification of Animals.

1. *Protozoa:* Animals that remain solitary cells: each composed of a cell that divides for a time and then requires conjugation, forming a zygote to enable it to divide further. Its life is therefore alternately somatic and gametic.

2. *Metazoa:* Animals derived from a zygote which divides. The products of division cohere, forming a tube.

A. The tube consists essentially of two layers

enclosing a continuous cavity. The walls are folded and perforated by many inhalent apertures and by one or more exhalent openings. A mesenchyme present . . *Sponges.*

B. The tube is composed of two layers separated by a structureless jelly only containing mesenchyme in the higher forms. Stinging-cells present. A single aperture for inhaling and exhaling water . . *Cœlenterates.* (Hydroid Zoophytes, Medusæ, Corals, Anemones.)

C. The tube is composed of three layers, the middle or mesenchyme layer arising early in life. Body bilaterally symmetrical. Tube with one (Planarians) or two apertures (Nemertines, Rotifers) . . . . . . *Acœlomata.*

D. Body composed of two tubes, the space between the two being lined by an organ that gives rise to the heart-sac, the kidneys and the germ-cells. This organ is the *Cœlom* . . . . *Cœlomata.*

SYNOPSIS OF CŒLOMATA.

1. Body segmented and produced into hollow but not jointed appendages. Cœlom extensive . . . . *Annelids.*
(Seaworms, Earthworms, Waterworms, Leeches.)

2. Body segmented and produced into hollow,

usually jointed appendages. Cœlom reduced to a small kidney-sac, and to the germ-cells *Arthropods.*

(Shrimps, etc., Insects, Millepedes, etc., Spiders, etc.)

3. Cœlom divided but not segmented. Body unsegmented. Appendages not repeated in serial order. Cœlom (except in Cuttlefish), as in Crustacea, *i. e.* not segmented . . . . . *Mollusca.*

(Bivalves, Univalves, Cuttlefish.)

4. Cœlom lobed, extensive. Body radially symmetrical, not segmented . . . *Echinoderms.*

(Starfish, Sea-urchins, Sea-lilies.)

5. Cœlom segmented. Body enclosing three tubes: (1) a spinal tube, (2) a digestive tube, and (3) a cœlomic tube. Between (1) and (2) a rod (notochord), the forerunner of the vertebral column; sides of (2) perforated by slits to form *gills* (Fig. 8) . . . . *Chordata.*

(Vertebrata.)

Classification of Vertebrata.

1. Notochord lost during development *Ascidians.*

(Sea-squirts, Fig. 32.)

2. Notochord retained or replaced by vertebral column—

A. Median (middle line) fins with supports. Paired fins without digits . . *Fishes.*

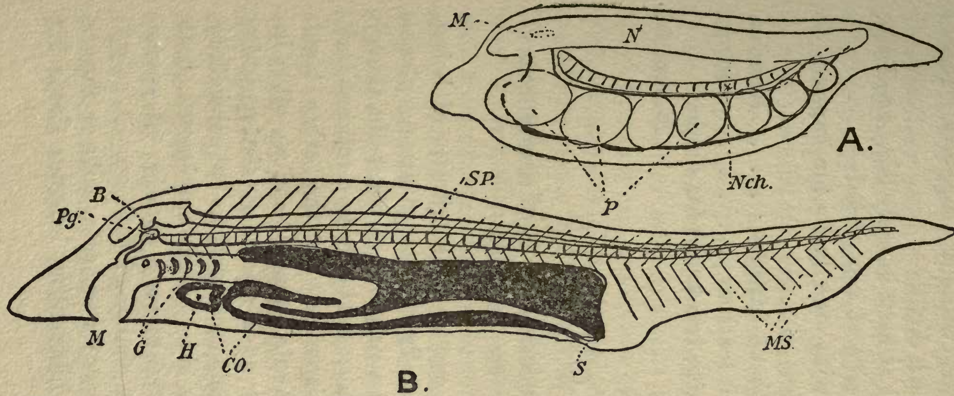

Fig. 8.—A. A further stage of Fig. 7, such as is realized in the development of lower vertebrates (*e. g.* Sea-squirts). The nerve-ridges have now united to form a nervous tube, the spinal cord (N). The pouches of the food-tube form a row of vesicles (P), which will presently give rise to the muscles and cœlom. Above the gut is a rod—the notochord (Nch) or foundation of the vertebral column. This rod develops as a groove from the middle line of the upper surface of the gut.

B. Diagram of a vertebrate as seen in longitudinal vertical section. The new mouth (M) has been formed, the old mouth being indicated by the gland (Pg) (pituitary body). The cœlom-sacs have now given rise to muscle-flakes (MS) and to the body-cavity and heart-chamber (CO and H). The nervous system is now differentiated into brain (B) and spinal cord (SP). The gill-slits are indicated by G.

B. Median fin without supports. Paired limbs with digits—
- α. With gills at least in early life *Amphibia.*
- β. Without gills at any period—
  - *a.* Skull with one knob for support to vertebræ.
    - *aa.* Without feathers . . . *Reptilia.*
    - *bb.* With feathers . . . . . . *Birds.*
  - *b.* Skull with two knobs for support *Mammals.*

CHAPTER II

MOVEMENTS, SUCCESSION AND DISTRIBUTION OF ANIMALS

MOVEMENT is one of the attributes of being. Though not generally recognized among plants, it is nevertheless a property of plant-life, though a property that is exerted only in a reticent fashion. In many animals, on the other hand, movement is a dominant note, and we often instinctively use it as a means of distinguishing animals from their surroundings when walking over the country side. Such movements, both in amount and finish, vary greatly. A sponge exhibits no active change of position. A polype or sea-squirt moves its tentacles only or shrinks into its shell, a hibernating hamster sleeps for

half the year and a scale insect never moves. On the other hand, a whale, a lark, or a dragon-fly is the embodiment of abounding energy and a hovering-fly the acme of poise. The principle of reserve, of not working up to breaking strain, is well seen in the usually slow movements of quadrupeds. A herd of deer moves slowly until an alarm excites them.

The chief reason for movement is to be found in the need for seeking food. Plants, living as they do, on air and water, can grow and multiply without obvious change of place. Animals are unable to make a synthesis of air and water. They require either solid or liquid organic substances, and only after analyzing these are they able to synthesize the products of analysis into living matter. Hence animals must either collect organic matter or go seeking it. This quest exposes them to many dangers: the fury of the elements, the attacks of enemies, the danger of being lost; and hence movements have to be adjusted to meet a variety of circumstances. The food of a young animal is not to the taste of an older one. Habits change and movements change along with them. Food, again, is not continually required. By day, in some cases, by night in others, there ensues a period of repose when the cud can be chewed or sleep obtained. The fall of the tide is the signal to thousands of

creatures for a period of enforced rest, to others of renewed activity. Hard winters in temperate or arctic lands cast many animals into a deep sleep. The dry season of the tropics induces a profound stupor in many others. These intervals of rest and activity induce many movements that are unconnected with food, and that are directed rather to the acquisition of comparative safety. The frog that spends the summer in lush grass seeks the bottom of a pond during winter. The earthworm descends the soil to escape frost. Caterpillars leave their dying food-plants and hibernate in moss or in the ground. The mud-fishes of South America and of Africa burrow in the bank at the approach of drought, and lie dormant until the next rains. The frogs of Australia dig holes with their ankles to escape the dry season. The Annelids and Crustacea of our coasts retire at the fall of tide into their burrows to escape desiccation. Movement, therefore, is directed not only towards sources of food but to self-protection. It is not a continuous phenomenon, but one subject to periodic stoppages. The time of the day, the season of the year, the phase of the moon, the temperature of the ground, influence movement profoundly: now enhancing, now inhibiting it, or directing it into new channels, in relation to the welfare of the individual.

In addition to the movements that conduce to individual welfare there is another class of motions that relates to racial well-being. Many animals, such as barnacles, hydroids, anemones, corals, are fixed, and only perform small vibrations within a short radius of their station. Some, such as the snails, bivalves and other unsegmented creatures, though not fixed, are sedentary and cover little ground in a lifetime. All these fixed animals, and the majority of the sluggish ones, have an active young stage. They hatch usually as free-swimming larvæ, the organization of which is usually very different from that of their parents (Chapter VIII). This active juvenile stage needs sense organs, digestive organs and perceptions adapted to a life more full of incident than that of their inert parents.

The object of this more moving period is not so much the quest of food as the colonizing of new regions. If the young were lethargic, the habitat of parents and children would soon be depleted of its food reserves. It is to the advantage of both and of the race that new regions should be explored and new colonies started by the explorers, and incidentally other advantages are secured. The tendency of sluggish life is toward the depreciation of delicate structure, and though the conservative power of structure is,

undoubtedly, great, yet in the course of generations, loss of eyes, of muscles, even of the head itself may occur as the result of a sluggish temperament and unchanged conditions.

Against this tendency the active young stage of animals is some preventive. It ensures that at least once, or for one period, the body shall be alert, the senses quick, the muscles taut. It involves a change to a new environment where the flow and ebb of tide, the denser and lighter water, the changes of surroundings are more marked. It ensures that the most adaptable of the family thus launched upon unfamiliar ways shall in at least many cases be the ones to survive and in new regions to maintain the race. The practice of movement by young animals not only fits them for their life, but keeps up the virility of the race. Animals do not play because they are young. They are young in order that they may play.

Animal life is, however, strangely varied, and its youth is often an inert phase rather than an active one. Where food is plentiful and easily acquired it is often found that the benefit of the race is fostered rather by sluggishness on the part of its youth and by activity on that of its age. Growth in all animals is rapid at first, slow afterwards: and there are many orders that devote their youth or larval stage to rapid growth fa-

voured by abundant food and little exercise. Insects form an admirable example of this adaptive growth. In the majority of insect orders, the parents are eminently active, the young eminently passive. In them growth and maturity have to be rapidly gained in order that brood after brood may possess the summer. Thus it comes about that movement is adapted to racial ends. In some animals and in some phases of growth it may be reduced or even lost; but what is lost in one stage is regained in another. The fundamental property, movement, is never wholly absent from the cycle.

Movements of Protozoa.—The oldest forms of movement are those performed by Protozoa; and consist of the extrusion of any part of the mobile body or the contraction of some especially motor process of it. In the former case the direction of movement is indeterminate, its rate slow and its relation to the substratum assured. In the latter, the Protozoa is carried rapidly through the water in a definite direction and is rendered independent of the soil. Such microscopic organs as serve to this end are like minute eyelashes and hence are called "cilia." In higher animals they are used either for the same purpose as in Protozoa, namely, to seek food or, if not strong enough for this, to inhale food from the surrounding water, and to expel from the body

noxious substances that tend to accumulate within it.

Cœlenterates.—In Cœlenterates, cilia are still the chief motor organs, but in this phylum we find a primitive kind of muscular tissue used for retracting the mobile part of the body and in jelly-fish for swimming. The cilia are of two kinds: those which create an inwardly directed current into the mouth and those which are constantly exhaling water through the throat-tube so as to keep up the circulation. In general, however, the Cœlenterates are sessile and not freely moving organisms, and in consonance with their sluggish habit the nervous system and sense organs remain simple. Only in the Medusæ are they highly and definitely organized.

Movements of the Higher Animals.—It is not until we reach the Accœlomata that muscular movement becomes the motive power of creeping. In this phylum a definite brain is associated with the habit of creeping with one end of the body constantly in front. But even in these animals movement is only fitful and slow. The Planarian glides away only to rest as soon as it reaches a shady corner or when day breaks. It trails the easily lacerated body behind it and has no freedom of action, and we, therefore, do not wonder that its parasitic relatives have so soon given up the habit of movement. It appears as

though mesenchyme were not an efficient means of producing sound muscular tissue, capable of bearing the body's weight as well as of propelling it rapidly. The advent of the cœlum brings the desired change. The most active animals are insects and vertebrates, two divisions of the Cœlomata, and it can be shown that the muscles of

P

Fig. 9.—The flying fish (*Exocœtus volitans*), to show the pectoral fins, which form an aeroplane during flight, and the small pelvic fins (P) corresponding to the legs of other vertebrates.

these creatures are derived from the segmented masses which lie between the gut and the body-wall in the embryo; in other words, from the cœlum (Fig. 8, B). Hardly less active than a fish is a cuttlefish, the most highly organized of the Mollusca, and it is just in this subdivision of the phylum that the cœlom attains the greatest development. Thus we may state as a general conclusion, though subject to certain qualifications, that the power of sustained rhythmic muscular

contraction is developed in the Cœlomata from cells which form part of the walls of the cœlom.

The simplest arrangement of the muscles takes the form of a double layer inserted into the skin, the outer layer being circular in direction and the inner layer longitudinal. By contraction of the first and relaxation of the second, the body is elongated and made thinner, whilst it thickens and shortens by the reverse action. The muscles may be segmented, as, for instance, in Arthropods, Annelids and Vertebrates, and the circular layer may be dispensed with as the body becomes more rigid; but the majority of aquatic animals move by alternately bending their right and left sides into a sinuous curve, and so gaining a fulcrum at the hollows against the medium in which they live. Thus, fish swim by lateral undulations of the muscle-columns and of the fins that run down the centre of the back and of the belly, and are assisted by a torsion of the tail-fin, which turns through a figure of eight. Very slow movements are, it is true, effected by backward strokes of the paired fins, especially of the pectorals (corresponding to our arms), but in rapid movement these fins are used rather for balancing and steering than for propulsion; and the muscles of the paired fins are merely local developments of the segmented body-musculature and therefore are cœlomic in origin. Hence

the fins move altogether if they move at all. There is no system of joints in a fish's fin such as we meet with in the limbs of higher vertebrates, for the weight of the animal is not felt, and propulsion, not sustenance, is the needful mechanical action.

When we come to land animals, and still more when the problem of flight is considered, the problem of weight has to be considered before that of locomotion. The lateral undulations of the body, even when aided by unjointed paddles or fins, are not sufficient to ensure rapid movement on land. Hence a system of levers has to be evolved, partly to support the body and partly to propel it. The use of joints becomes a necessity, and we find that all active terrestrial animals, except snakes, have jointed limbs. Insects, for example, have three pairs of jointed legs, the first pair for haulage, the middle pair for balance and support, and the last pair for thrusting. Each leg becomes converted into a more efficient limb than is found in their remote connections, the Millepedes, or their still more distant relations, the Crustacea. In these creeping forms the legs are numerous, the joints of the legs approximately alike; whereas in insects the body is nicely balanced about its middle or thoracic part, and each leg is made up chiefly of a strong femur or thigh, a long shank or tibia, and a

jointed foot or tarsus, suitable for obtaining a firm and yet flexible grasp. The body of an insect is, in consequence of the length of the tibiæ, raised above the ground, and therefore requires constant adjustment in order to maintain its balance. To meet this end the nervous and muscular systems are highly organized. This example is sufficient to show that the general result of terrestrial adaptation is an advance on that requisite for aquatic life.

Vertebrate evolution is, however, the classical example of this result. The critical point in the history of this phylum is passed when its members migrated from water to the land. The step was taken by the ancestors of the Amphibia (that is, the frogs, toads and salamanders). In them the breast-fins of the fish have become the jointed fore-legs, the pelvic fins have become the hind-legs. As in the insects, the limb has become segmented into three portions, a thigh, shank, and foot, and the number of webbed rays has diminished to five or four, the end joints of which become free and form the digits. These are unable to perform the movement of opposing the first digit to the rest, which is such an essential factor in the usefulness of our own hands, and the wrists and ankles are stiff. How this great change from the fish-fin to the five-fingered hand occurred is, at present, just as obscure as the mode of conversion of the arms of reptiles into the wings of birds.

The answer can only be supplied by further discoveries in the geological history of the order, and though this history can be traced back to the time of the Coal Measures, we find the earliest Amphibia as sharply marked off from the fishes by their feet as they are to-day.

The earliest Amphibia give rise to two important orders, which have undergone very different lines of evolution. In one direction there were evolved (Fig. 10) the sluggish newts, salamanders and frogs, which still scarcely raise themselves above the ground; some, indeed, have degenerated in the matter of their limbs, and now live in equatorial countries like earthworms in the soil, having lost every trace of their appendages; others, the water-newts, use their feet only in a vague and tentative way, depending chiefly upon the tail and lateral body-muscles for swimming movements. The salamanders, emancipated from the water, are confined to damp woods or the borders of the snow-line, where perpetual damp can be secured, and these move slowly without the use of their muscular tail. The frogs and toads develop the tail in the larval or tadpole stage, when they still swim like fish, but absorb it for the building up of the powerful hind-limbs when the period of metamorphosis ensues. Though capable of active movement and endowed with keen senses, these Amphibia have

done little to acquire a higher place in nature than their forefathers of the Coal Measures.

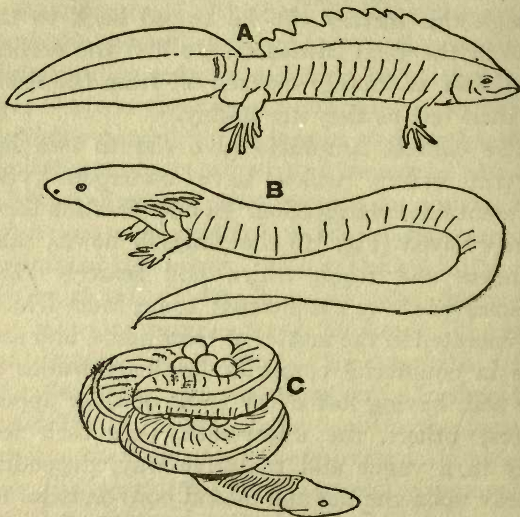

Fig. 10.—Group of Amphibia.

A. Male of crested newt *Triton* (*Molge*) *cristatus*, showing the high dorsal fin and caudal fin encircling the tail. The segmented muscles are seen by the transverse lines crossing the body. (× 1.)
B. *Siren:* a North American newt which has lost its hind-limbs and retained its external gills. (× $\frac{1}{2}$.)
C. *Ichthyophis:* a Central American amphibian that has lost both pairs of limbs. It belongs, therefore, to the Apoda, or amphibia which live in earth and manure-heaps. The specimen shows a female guarding her eggs. (× $\frac{3}{4}$.) (All after Gadow, *Cambridge Natural History*.)

Evolution of the Reptilia.—To this, the second group offers a complete contrast. The

reptiles form, indeed, a sister order to the Amphibia, descended as they are from an early stock of newt-like forms, but with how different a career. Their emancipation from aquatic life was more rapidly completed, their locomotory powers early attained a degree of cultivation that no Amphibian has ever equalled. By its darting movement a lizard easily evades the hand stretched out to capture, and the slow and quick movements of a snake have an almost uncanny elusiveness and strength. But it is rather in the extinct groups than in the modern forms, that reptiles show their variety and grace of movement. From an obscure beginning (of which the *Hatteria*, or rare Norfolk Island, New Zealand, *Tuatara* is the sole representative), the reptiles flowered out into a vegetarian and carnivorous beast-like race that flourished in Africa, Europe, and Asia. In these creatures the body was carried clear of the ground and had probably the movements of a dog. So close indeed is the similarity of many of the bones of this early group to those of mammals that these reptiles are termed the Theromorphs, and have been thought the putative parents of the highest animals. From the Theromorphs onwards the history of reptiles is full of incident. Some groups attained the mastery of the land, others that of the sea, and one group at least learned to fly. In consonance with these deviations of habits, modi-

fications of structure went hand in hand. Vast length and bulk characterized the most successful terrestrial and aquatic orders, but did not prevent the co-existence of many small races. In

Fig. 11.—One of the extinct flying reptiles in the position of rest (*Pterodactylus longirostris*), showing the immensely elongated "little" finger which bears the wing membrane. (After Seeley, × ½.)

the Dinosaurs there are giant forms, whose remains are to be seen at Brussels, that stand on their hind-limbs and could reach with their hands the juicy shoots of trees, twenty feet high, and there are delicate, almost bird-like forms not bigger than a gull. In these Dinosaurs the bipedal habit, now-a-days only retained by birds, kanga-

roos and man, was the rule. On the other hand, the flying reptiles or Pterosauria were also of very different kinds, all of which were perfectly distinct from any animals that exist to-day. The "little-finger" in all, is enormously elongated and strengthened, and supports a wing-membrane upon its inner edge. Also, unlike birds, both the fore and the hind-limbs are clawed, and may be long like those of deer, or unequal in length like those of bats. In size these animals varied from that of a wren to vast creatures twenty feet in spread of wing. No less varied were the "whales" of that period. Many and distinct orders returned to the element from which ages of evolution had removed them, and here they preyed on their less emancipated associates, the fish, and acquired varied forms. Some, with elongated necks and paddle-like limbs, have no counterpart in other ages. A few, the Ichthyosauria, had short necks and long heads like the true whales, and in all these aquatic reptiles the tail was the chief swimming organ. Such mastery of the earth, air, and sea would appear to exhaust the possibility of evolution. The reptiles seem secure for ever against competition. So little do we see of the forces that displace kingdoms that we even now know nothing of the causes that lead to their disappearance, an exit as impressive as anything in nature. Lizards, tortoises, crocodiles, and

snakes alone survive to maintain the traditions of a mightier past.

LOCOMOTION IN THE MAMMALIA.—The history of mammals is an equally moving spectacle. Beginning probably in the time of early reptiles, the first mammals were a feeble folk. Their earliest known traces occur at the heydey of their saurian relatives, and show some to have been small opossum-like beasts, others were probably different from anything that now exists, but it was not until the fall of reptiles that the mammalia assumed their variety and attained their commanding position. Their modes of progression have taken in the main two forms: increased running and leaping powers, due to elongation of the limbs, shortening of the tail and development of large extending and flexing muscles; and a more or less completely bipedal form of locomotion by which the fore-limbs are set free for grasping, and in consequence of which the manual arts have become possible. Such partial emancipation of the arms for the support of the body is seen in the kangaroos, the extinct sloths, the lemurs, monkeys and apes. In man alone is it complete, and has led, as much perhaps as any single structural feature, to his evolution, when we consider the immense effect of signs, words, of drawing and art and of manual work, in bringing about civilization.

Special forms of locomotion are rare. Bats are the only true fliers in the order, but at least three other orders have members in which a large supporting membrane stretched between the arm and the body enables them to make flying leaps. The flying phalangers of Australia, the flying squirrels of Africa, and the "flying Lemur" or *Galeopithecus* of Malaya are the best known examples. The whales illustrate another means of locomotion. In these mammals the hair is reduced to a few bristles and the hind-limbs have disappeared; the body terminates in a horizontally placed pair of flukes made up of the tendons of the abdominal muscles, and it is by the action of these muscles that the stroke is effected. The enormously increased length and bulk of whales over those of their terrestrial allies is an interesting commentary on the need for supporting and limiting the weight of the body on land. There is no doubt that whales have been descended from terrestrial ancestors, although, as in so many other cases of profound change, we are not as yet able to point with certainty to the ancestral group. But there is also no doubt that the increase in bulk occurred after the adaptation of aquatic life. The weight no longer has to be supported by muscle, and there is no such limiting factor as existed before in the strength of the limbs. Hence the possibility is

given for greatly increased size. The factors, however, that determine why a rorqual can attain seventy feet in length, whilst the porpoise never exceeds a few feet are still largely uninvestigated.

One of the favourite starting-points for the origin of whales has been the family of which seals are the best known members, and these animals afford an excellent example of terrestrial and aquatic life. There are two entirely different kinds of seals, the eared seals, or sea-lions and sea-elephants, in which the hind-limbs are bent and are used for progression on land, and the true seals, in which the hind-limbs are extended stiffly backwards and are useless except for swimming. In these animals swimming is carried out by lateral undulations of the trunk-musculature. In this case, as in the whale, the ichthyosaurs, the crocodiles and the snakes, we find that the means of locomotion are essentially the same as those which are employed by fish.

Influence of Temperature on Movement.—Adaptive locomotion influences every part of the body and is in turn determined by almost every part: and in no way is this more felt than in the adaptation to resist changes of temperature. The lower vertebrates, like the invertebrates, show very little adaptation to

attain this desired end. It has been found that fish, for example, breathe less frequently in cold wintry weather than in summer, and are consequently very inactive. They, however, make amends for inability to effectively resist changes of temperature by migrating into deeper water, when the local conditions become unfavorable. On land and in fresh water such changes are naturally more acute, and we find few animals that can prolong their activity through winter and summer alike. Frogs and reptiles fall, as the temperature falls, into a winter sleep, insects disappear and the hum of summer life becomes inaudible. Such long periods of inanition are great drawbacks to animal prosperity, and it is a significant fact that the two most highly organized and successful classes, birds and mammals, are the two which are warm-blooded and able to maintain their activity when their more changeable relatives are in profound stupor.

The factors that have led to this desirable result are very complex. Not only must the heat of the body be retained by some non-conducting material such as blubber, hair, feathers or clothes, but there must be some regulating mechanism to maintain that constant internal temperature which is such a marked peculiarity of these warm-blooded creatures. No doubt

there are some fish, such as the tunny, just as there are some insects (bees) and snakes (Python), which can raise their temperature above that of the water or air in which they live, but they cannot regulate the heat so as to remain uniformly warm in an inconstant medium. In a low temperature all these imperfectly warm-blooded animals became inactive and may die. The heat-mechanism of the mammals and birds is an internal and largely nervous one. It consists in having good heat-producing muscles and glands, and in possessing also the heat-regulating nervous mechanism for governing the production and the conduction of the heat produced by oxidation. No wonder, therefore, that in time of severe weather even some mammals are tested by the change of temperature beyond the limit of their nervous control and fall into a state of intermittent or prolonged stupor, when their temperature goes down to a few degrees only below that of the air. The cold-temperate regions are perhaps the most trying in this regard. Even the arctic has a less rigorous and rapid change and range of temperature than our own, whilst the warm-temperate and tropical zones are, on the other hand, the most uniform. In this comparative uniformity and variability of heat we have one factor in the distribution of animals and

one explanation of the behaviour of animals that have migrated from the warmer to the colder parts of the world.

Distribution of Marine Animals.—The most uniform medium both as regards constitution and conditions is undoubtedly the ocean, though there is far more variability in this seemingly monotonous life than appears at first sight. If we divide the sea into three portions by lines drawn through latitude 40° north and south of the equator, we have a belt of warm ocean water in the Atlantic and Pacific oceans, while north and south of this lie the temperate and the arctic caps of water. Speaking generally the fauna of the warm belt is distinctive and fairly uniform in all parts of the world, whilst that of the two caps is again uniform, but quite different from that of the equatorial zone. Many of the fish, crustacea, and the minute animals of the cold, northern seas are met with again on the coast of Patagonia and of South Africa. The arctic right whale has its counterpart in the southern right whale of the antarctic. The movements of all these boreal and hyperboreal animals follow the tracks of cold water: for example, the arctic whales follow the cold Labrador current that sets down the Newfoundland coast. In the same way the warm-water fauna follows the

drift of the Gulf Stream and of other branches of warm ocean currents, so that from time to time West Indian fruits, turtles and fish are occasionally stranded on our western coasts: and still more commonly on those of south-western Europe. Each fauna appears to die out, however, if transferred to sea-water of a

Fig. 11A.—*Basiliscus:* a lizard from Central America. The specimen figured is a male, and is distinguished by the possession of a high dorsal crest on the head, body, and tail. (After Gadow, × ⅛.)

different density or temperature. The vast majority of marine animals have no power of altering their constitution to suit water of a new degree of salinity. Their movements are controlled so as to keep them in the stream or drift of that kind of water to which they are, as it were, attuned, and a very slight change in the water is fatal either to themselves or to their offspring.

Marine animals are, on the whole, of such delicacy of constitution, of such nicety of discernment as to need and to keep in the stream or body of water which only a qualified chemist is able to detect as differing from the rest of the ocean in which it lies as a layer or a deep isolated tongue. It is therefore a matter of wonder that fresh-water and terrestrial animals should be able to resist gradually the still more pronounced fluctuations of temperature that occur in their environments, not only by day and night, but those seasonal changes of dry and wet monsoons, of winter and summer, and, above all, those still greater secular changes in climate of which the Ice Age is the best known example. If animals generally can best live, move and work out their life-histories in a fairly uniform climate, then the tropics and warm-temperate countries would seem to be the most suitable ones for them, and, in fact, the distribution of terrestrial life shows that the richest fauna is that of such countries. Not only do the tropical and sub-tropical lands possess the most numerous and the most varied animal life, but they appear to have furnished the cold-temperate countries with most of their animals. Our reptiles are an impoverished group of the abundant European snakes and lizards, and these in turn are but a section of

the tropical Oriental reptilia. In the same way tropical South and Central America is the zone of the new world most favourable for poikilothermic animals, that is, such as are of a variable temperature, and as we proceed northward into the states or southward into the republics the variety of animal life diminishes until the arctic in the one case and the inhospitable Patagonian lands in the other, contain few animals except the mammals and birds, that are able to withstand by their homoiothermic mechanism (or constant temperature) the rigours of cold and of change.

This long explanation has been needed in order to suggest why it is that the ability to support life and to flourish in a country that changes much during the year, has enabled birds and mammals to supplant reptiles and to assume the premier position amongst animals. Birds have excelled reptiles in virtue of their constant internal warmth. This enables them to range over the whole world, to remain active throughout the year, to rear their young quickly, and therefore to become subject to a far greater range of experience than can fall to the lot of their more sluggish and more tropic-bound relations—the tortoises, crocodiles and lizards. In the same way, mammals have excelled reptiles by reason of the same homoiothermic

faculty, but in their case the facilities for locomotion are more limited. The superiority of mammals is based on their accumulation of modifiable experience or educability, on their association in flocks or herds, and on their size and strength. In either case the dominance of birds and mammals was easy in the cold-temperate and arctic lands, for these could not have been peopled by reptiles, and could only support animals that were able to withstand severe fluctuations of climate.

Nevertheless these reasons are not sufficient to explain why the great reptiles died out, for it seems probable that some of them (the flying-reptiles and the whale-like forms) had actually evolved a mechanism for maintaining a constant bodily heat and were therefore as independent of their environment as birds or whales are to-day. The same difficulty meets us in explaining the disappearance of any highly-organized system. Lack of brains, lack of adaptability, some innate tendency to regress after high specialization had been attained, competition with other rivals, impaired birth-rate, these and other hypotheses have all a certain weight but fail as a general explanation of extinction. We see the passing of a race apparently built for eternity and "all that mighty heart is lying still."

Summary.—A summary of the chief factors in the history of animal locomotion would include the following. For sustained movement a certain constancy either in the medium around animals or in the temperature of the animal itself, is requisite. Hence the sea is the most favourable medium for most animals. On the land, predominance is assured for those groups (birds and mammals) which have succeeded in forming an inner, hot medium independent of the temperature of their surroundings. This constant temperature is, however, only sustained by plentiful food—hence innumerable devices to ensure its up-keep. Migration is one of these devices, *e. g.* the northward spring migration of many birds in quest of food and nesting sites. In autumn these birds migrate southwards, returning to the warm countries in which life is then easier to sustain than in the changing climate of the temperate zones. Warmth then assists birds as it does to a greater extent the cold-blooded animals. Movement, therefore, partly explains the distribution of animals.

For the great majority of animals driven by competition to adopt fresh water or terrestrial life, the seasonal changes of temperature, of food, and of moisture lead to intermittent movement. Winter, drought, lack of food cause

sluggishness and stupor if not decimation of the summer brood. Hence the lack of high organization in many groups: and hence also a vast array of adaptive measures for protection to old and young during the testing season (for example, burrows in earth, manure, etc., adherence to man's dwellings, cave-life, moss-life). These contrasts are least felt in the tropical, sub-tropical and warm-temperate countries, and it is here that animal life varies more and attains higher development than further north and south. The temperate zones are colonized chiefly by enterprise from the warmer countries.

Movement is a property of being. Its effectiveness reacts on the whole body. Movement in a definite direction, implying a "head," right and left sides, and a creeping surface, is first seen in the Planarians and their allies: effective movement in the segmented worms and Mollusca : sustained movement in insects and fish. The evolution of terrestrial animals must have occurred several times and led to the Amphibia, Reptilia, birds and Mammalia. The Amphibia and Reptilia are probably sister-stocks, the first still leading the life of the swamp, the second emerging into the open and even taking to flight. The reptiles exhibit all the modes of locomotion and have even gone back

to the rivers and seas. Their age of mastery is a thing of the past, though it is inexplicable why they succumbed. Birds are the most facile of all animals in adopting a suitable change of environment by migration or in surviving a changing one by their almost omnivorous habit, and are shielded in either case by their constant temperature. In mammals the brain has developed far beyond that of other animals or even their muscular and governing needs. They and they alone appear to be able to accumulate and modify their experience and to succeed in establishing themselves, not so much by following, like birds, the line of least resistance, as by subtle adaptations which enable them to hold their outposts and to endure both the arctic and tropic without flinching.

CHAPTER III

THE QUEST FOR FOOD

"All things flow," said old philosophy, and indeed the appearance of stability in nature scarcely hides essential impermanence and fluctuation. The mountains fall, worn down by ice, water, and the attrition of ages; new ranges arise, are piled up by the sea on rising coasts and

lifted beyond the action of waves into that of frost and snow by the crumpling of the earth's crust. Material and energy are building up and pulling down the furniture of the earth, yet so slowly that their action seems ineffectual.

METABOLISM.— Organic nature is more palpably impermanent. The may-fly endures for a day, a thread-worm for a week, a planarian for a month, a worker bee for four months, a shrew and a pellucid goby for a year, a coral for twenty-five years, a man for seventy years, a bird for a hundred years. Each moment of these lives is filled with a double action: one phase destructive, the other constructive, and life is the outcome of the balance between these two phases of action. As in the case of mountains there are the matter and the energy to be considered: and the problem of life is, first, what matter is lifted to the point of living, and second, what forces lift it to that point and then hurl it down in order to give place to its successors. The seeming stability of an inert man or reptile is deceptive, like that of a volcano. There is hidden beneath the placid exterior a successional flow of constructive and destructive events, and the placidity is due to the enormous reserves of force and of material. The mountain of flesh is wearing down, but like the mountain of rock the process is slow. As each range of tissue goes silently to its death

it is renewed by fresh stores of material from the reserve funds of fat or starch or egg-white. These larders are of generous size and are distributed in many ways; but, long before they are depleted, the body becomes hungry and cries for more, as though aware of working near the breaking strain. Then out of a winter sleep of months or the nocturnal sleep of hours, the body wakes and casts about to renew its larders.

The quest for food is thus involved in the very constitution of matter and the wearing attribute of energy, and is enhanced by the fact that we bank our income and draw upon our deposit by small drafts. This system provides against the great day of adversity; enables the winter sleeper to survive its long stupor; the migrant to make its long marches; the hot-blooded to keep its temperature even when food fails for days. The most important of all such drains on the reserve fund of nourishment is the feeding of the young. The egg, full of meat, is the symbol of organic life in its provident reserve, latent capacity and independence.

But not only is food-material dissolved, built up into living substance and analyzed into waste material, there must concomitantly be a cycle of energetic processes. Food, animal food, is energy stored in material that has embodied an earlier system of such changes. It not only replenishes

the worn-out material, but it reinforces waning energy. This fresh supply is partly reserved, partly used for current emergencies. It is banked with the reserve food-supply and it may evolve heat. If the animal is a homoiothermic one, it will require more continuous supplies of food than a cold-blooded one in order to maintain the constant temperature, to replace the vast quantities of material that go to waste, and also the expenditure laid out in eggs and milk.

Importance of Plants.—From the point of view of biological economics there are three sources of food. Plants (including bacteria) furnish the first of these; organic fluid media (either the result of plant-action in water or the fluids of animals) the second; and other living animals the third; that is, vegetables, drinks and flesh. In all cases the plant-world furnishes the basis, and we may say that animals depend absolutely on plants for their renewal of matter and energy. To understand animal economics, therefore, we must glance for a moment at the abundance and distribution of plants.

The basal and omnipresent forms of plant life are bacteria, blue-green algæ, and their allies, the yeasts and moulds. Bacteria occur in all seas and in all soils. In a moist, warm soil there may be 50,000,000 per gramme, and the whole fertility of nature above ground and under water

depends on these microscopic organisms. Blue-green algæ are the first organisms to populate devastated regions, the first to form soil on rock and to render the barren land fertile. Yeasts are minute bodies that lie scattered over the earth and trees and that are blown into our houses as dust. Yeasts and bacteria break down organic solutions or bodies, and are able to set up extensive changes leading from organic to inorganic substances (chiefly carbonic acid and water) without undergoing any appreciable loss of material or energy. These are the sensitizers of nature, the pullers of triggers, as it were, that by their mere presence set going vast exchanges of energy and alterations of chemical structure. Then we have other moulds that live in water and on land, forming networks of delicate strands in every fertile soil and densely massed around the roots of trees, lilies and many other plants. Their spores are in every atmosphere, and we have only to let a room remain unused or woodwork to become damp in order to discover the mouldy smell or the dry rot that have been kept at bay during the more hygienic *régime.* Then we come to the green plants that can only live in light, but that, given light, can synthesize water (the complex water of nature, not extracted "pure" water) and carbon dioxide into an aldehyde or simple form of carbon compound. This

compound is then converted into a form of sugar, starch or oil, and ultimately this is built up into a living molecule. In the sea and in fresh water, millions of such green plants live alone or in chains, such as those minute algæ which discolour our garden paths or farmyards. Others, forming a combination with certain moulds, produce the dual organism so familiar under the form of lichens that cover the uplands of Scandinavia and that eat into the very stones of the limestone country. Still more important from the point of view of animal provender is the multitude of diatoms, unicellular algæ enclosed in a sculptured flinty case or box, which swarm in both sea and lake, often discolouring the water.

Capture of Simple Plants.—Upon this prevalent, minute plant life in sea, pond and soil animals depend for their food. All that is necessary for its capture is the provision of a throat capable of gulping down incessant draughts of water or mouthfuls of soil, of straining off the plants and of discharging the rest. Active search is hardly required, and in fact the great majority of such feeders are fixed or move but little. The Protozoa, many hydroids, jelly-fish and corals, the lower Crustacea, especially the Copepods, Barnacles and Phyllopods (the group of which Daphnia is a member), the sponges and various encrusting forms of animal life feed in

this way. Bivalves and lamp-shells inhale a ceaseless current of water for the same purpose, whilst the majority of snails and slugs browse upon algæ or higher forms of plant life. Soil, whether sea soil or land soil, being tenanted by bacteria and fungi, is swallowed in great masses by earth-worms, sea-worms, and sea-cucumbers. This, then, is the first and simple method of animal nutrition: drinking the water and eating the soil. On such a simple diet, obtained with so little exertion, the lower orders of all the great phyla or divisions depend.

Herbivorous Habits.—The gradual development of land plants, however, sets up certain difficulties in the way of a purely vegetarian diet for terrestrial animals. Aquatic plants, and especially algæ, are comparatively easy of digestion, but land plants, in order to withstand their own weight and the forces of wind, have developed stouter investments, *e. g.* coarser vessels, woody fibres, and these adaptations cause much plant food to be relatively indigestible. Hence we find that herbivorous habits are less commonly the rule amongst the lower terrestrial animals than amongst their aquatic allies, and that a choice is often made of the more primitive and less hardened plants and of the more succulent ones amongst newer kinds. Ferments for dissolving the cuticle of leaves have been evolved,

and in special cases these are so effective that wood-boring insects of many orders are known. But the difficulty of vegetarian diet is well shown in the mammalia, for it is chiefly the Rodents and the Ungulates, with their numerous and complicated grinders and their frequently complex stomach, that are able to subsist entirely on the shoots of plants. All other vegetarians are either only partially so or select chiefly the fruit and seeds, to the exclusion of the tougher leaves and wood.

Of these herbivorous land animals, insects, especially insect-larvæ, and molluscs, birds and mammals form the chief portion. There are, it is true, aquatic insects which pass the whole or all but their final stage of existence in water, but these form an insignificant section of the vast class. Probably half a million different kinds of insects are terrestrial; the most numerous being the Lepidoptera, the beetles and two-winged flies; ants, though not so varied, are immensely numerous individually. Each of these half million insects required one kind of food when young and usually a perfectly different kind when grown up. The food plants of the larvæ are usually well defined. The common white butterflies select Cruciferæ; the "blues" select violas; the white "ants," or termites, wood. The most varied methods have been

adopted for comminuting the food in order that the dissolving ferments may work effectively upon it. Thus jaws become a necessity, and in most insects there are three pairs of such which work from side to side and not like our own, from below upwards. The first pair, or mandibles, are the most effective, the second and third serving as a sort of underlip. By the aid of these mandibles and maxillæ, as they are termed, fungi, lichens, leaves, and even the wood itself are gradually devoured. A few groups of wild plants appear to be exempt from attack, Ferns and their allies generally being the most noted exceptions, but when grown in captivity or transferred from their native soil to gardens they often lose their power of resistance or quality of repugnance.

Interaction of Plants and Insects.—Plants, however, offer another and still more attractive source of nutriment: the sap and the pollen. For some reason, not thoroughly understood, these sweet and delicate foods are rarely sought after by larvæ. Sap and honey form the food and drink of most winged insects in their final phase. Pollen is the food of bee-larvæ and of some wasps. To gather this, far more complicated mechanism is essential than a mere chewing arrangement. A tube and a suction-pump have to be evolved in order to drink the

sap and baskets to carry the pollen. Hence we find that the mouth and jaws of most mature insects are differently and more highly organized than those of mandibulate orders and of larvæ. In butterflies and moths the first maxillæ are drawn out into a highly sensitive trunk. In bees, flies and other orders the second maxillæ are similarly modified. Such exquisite adaptation has taken long ages for its execution. Hand in hand with it has gone a remarkable finesse in structure generally. The brain in such insects is enlarged and lobed; the eyes grow by addition of new facets throughout life; the power of flight is perfect; the muscular control sustained and delicate.

Insect-fertilizers.—In their search for the nectaries of honeyed flowers such insects perform memorable service to the plants they visit. As a bee enters into a foxglove or snapdragon it brushes against the anthers that lie along the hooded petal, and in doing so dusts itself with pollen. As it works down the column of flowers it brings the pollen from one against the stigma of another and cross-fertilizes it. The result is that such plants as a rule bear more and better seed than self-fertilized flowers of the same plant. In fact, many plants take pains, as it were, to avoid self-fertilization and to ensure the visits of insects. Flower and insect have reacted upon

one another; the flower acquiring odour, streakiness of colouring, modifications of shape and size, rhythmical opening by day or by night; the insect developing a complex "tongue," hairy body and legs, acute sense of smell and probably of sight. The correspondence between the two sets of modifications may be so close that one insect only serves to fertilize a particular flower, as the Pronuba-moth that effects the crossing of the Yucca-palm; and a certain wasp in the case of the Indian fig. Further information on this fascinating subject should be read in Darwin's classic and the recent work of Knuth.

INSECT-PARASITES.—Another method of obtaining the sap from plants is adopted by the immense group of Hemiptera, the order of insects to which Aphides, Frog-hoppers or Cuckoo-spit insects and Scale insects belong. A similar method is practised by many dipterous insects. It consists in the puncture of plants by the aid of a stylet or group of stylets, and the subsequent sucking of the sap into the narrow tubular throat. The Hemiptera possess a pair of second maxillæ specially modified to form a lancet-like instrument or a piercing hollow spine. The mosquitoes, on the other hand, have three pairs of slender stylets which cut a wound and inhale the sap. Such insects abound in all countries, and, being able to find sufficient nourishment in a single

plant both for themselves and for several broods, they often acquire an extremely sluggish disposition, either dispensing with wings altogether or developing them only in the case of the male or of certain broods. Thus the scale insects which are common on oranges, lemons, tomatoes and other plants are immobile; the green fly rarely move, and drift rather than fly over the countryside. Mosquitoes, however, and other piercing Diptera, have retained their active habits, and large companies of males may often be seen performing complex evolutions over a river or forming a dense cloud over the country. The food of these swarms is still little known, but it seems probable that it differs from that of the more sluggish female mosquito since the male has fewer piercing organs. Either, therefore, he, like many other male animals, takes no food and lives only a short time, relying for sustenance upon the reserves accumulated during larval life, or he sucks with his feebler mouth-parts the sap that exudes from injured trees or from the nectaries of flowers.

Blood-sucking Insects.—This difference between the piercing mouth of the female mosquito and the simpler mouth of the male is the prelude to a tragic episode in animal life and in human life. In all insects the production of eggs in rapidly recurring clutches causes a great drain

upon the reserve-material of the female, and it is advantageous to her and to her race if a more stimulating or more abundant food can be substituted for a less nutritious one. This advantage is emphasized if such food can be obtained during the spring and summer, since heat determines the period of egg-production and hastens the development of the young. Mosquitoes and other insects have discovered that stylets will pierce hide as well as bark, and that warm blood is a food combining the advantage of stimulating nourishment with that of warmth. Hence the origin of the blood-sucking habit. Such a habit, however, carries with it many complications. If, for example, the blood of the host is charged with protozoa, the female mosquito becomes infected by protozoa, and when sucking the next host transfers some of the parasites to that host and so infects it. Blood-sucking insects, mites and ticks, have thus come to be regarded as one of the most dangerous sources of dissemination of disease and the only means of spreading such appalling inflictions as sleeping-sickness, yellow fever, certain kinds of plague, typhus fever, blackwater fever and other tropical diseases. The subject is too extensive to be dealt with here, but full references can be obtained in Sir Rupert Boyce's recent works.

THE CARNIVOROUS HABIT.—The quest for

food has led many groups of animals to adopt a carnivorous diet.

The habit probably began in the sea, since the floating and drifting life (plankton) of the ocean is not only composed of minute algæ and bacteria, but of the myriads of small or young animals that, as we have seen, feed upon this fundamental vegetable soup. Hence the filtrate left stranded on the throat of a plankton-feeder is partly animal and partly vegetable. Moreover, certain plankton feeders, particularly Copepods, occur in such swarms as to attract the attention of many fish. However the habit has been evolved it is certainly a very old one and has probably been re-discovered and adopted time after time in animal history.

Circulation of Food.—Briefly we may recapitulate the circulation of food in the sea or lake as follows. First, bacteria capable of fixing nitrogen and living upon inorganic compounds but creating organic ones. Then, bacteria living upon these organic compounds and exuding others; algæ needing light, carbonic acid, and salts, but flourishing better in an organic medium, or at least one with a certain quantity of nitrates, produced in turn by the bacteria. In such a medium diatoms abound and microscopic algæ multiply exceedingly, and upon them animals of the most varied kinds depend for food: the

young or larval stages of nearly all marine animals requiring this diatom and algal food and rejecting all others. It is, to them, their milk, without which they cannot grow or develop. Thus the shores and the high seas are full of thirsty throats, drinking the sea, exhaling the filtered water and swallowing the residue. These delicate feeders are themselves in turn the food of others. Fish, such as sole, feed upon bivalves; the mackerel, mullet and herring on Copepods; whalebone whales engulf swarms of Pteropods or sea-butterfiies (floating molluscs of the high seas) and pelagic Tunicates or sea-squirts. Then fish themselves are preyed upon by larger forms. Man himself is their greatest enemy; dogfish and sharks, angler-fish and wolf-fish, are the carnivores of the sea. Gulls and gannets, puffins and guillemots consume vast numbers of fish-fry, smelts, pilchards and sprats.

In a similar manner the cycle of economics is completed on land. Bacteria are the source of soil-fertility—the whole of agriculture is dependent upon the abundance of these invisible particles. Soil produces vegetation—algæ, fungoid, yeasty, cryptogamic (ferns, mosses) and phanerogamic (pines and flowering plants). In soil and close to the ground are the primitive vegetarians—the simple, flightless insects (silver-fish, beetles, ants), the millipedes, the earth- and

tree-worms, the snails and slugs. These cannot simply drink their food like their representatives in the sea: they have to seek it, and they need jaws to cut it up. More highly organized than these are the vegetarians that devour leaf and fibre, that suck nectaries and that puncture the wood-vessels in order to drink the sap; that rob our orchards and hedgerows of fruit and seed and split acorn and pine-cone for the kernels. These two classes of vegetable feeders constitute a vast assemblage of animals, whilst a large number are carnivorous, especially in spring. The mole, the thrush-family and redbreast devour the primitive worms. Tits, migrants and, in fact, land birds of all kinds are insectivorous during the nesting season. Ant-eaters, shrews, bats and bears depend largely on an insect dietary. Insects, in fact, correspond economically to that vast host of delicate feeders of the sea; and larval insects, being especially easy of digestion, are the most attractive and fattening food for nestlings. Hence the great swarms of migrants from the warm temperate countries to cold temperate and arctic lands in the short spring and summer; for in north countries not only is the supply of larvæ great when in warmer countries it is lessening but owing to the light-conditions of the North during the summer, a longer working day is assured in which to collect

stores of food to stay the constant hunger both of parents and of their young. When the nesting season is over many birds become vegetarians again (such as sparrows and rooks), but nearly all the migrants are insectivorous throughout the year.

Spider-webs.—The habits of spiders require especial mention, owing to their habit of making burrows, sheet-webs and wheel-webs, for entrapping their prey. The habit probably began by the burrowing spiders lining their retreat with silk and enclosing their eggs with a silken case in order to carry them about. Such spiders do not spin webs but jump upon their prey by night and enclose it with a gummy envelope. These spiders began hunting above ground, but still constructed a tubular retreat in which they lurk and from which they rush upon their prey. Loose, irregular flat-webs were probably the next stage, and under these the spiders lie, back downwards. Last of all come the geometric spiders that construct the orbs or wheel-webs with which we are all familiar.

Rapacious Animals.—The number and variety of land animals that feed upon others higher than insects are very limited. Owls and kestrels keep down the threatened plague of rats and mice, even though they may now and again carry off a young bird. Ravens and eagles are

more rapacious, but are so rare in this country as to do little harm to lambs in most districts. Foxes and stoats are capable of lustful killing, but these and the larger carnivora and snakes are among the comparatively few terrestrial orders of the animal kingdom which seek their prey, and in contrast to them are many vegetarians—the monkeys, lemurs, rodents, ungulates, sirenia (sea-cows); the bears and badgers; all the hard-billed birds; most lizards and tortoises.

CHAPTER IV

HOW ANIMALS BREATHE

There is a true sense in which food is a source of energy. Just as we feed fire with coal or oil, so the fire of life has to be fed with carbon in the form of starch, oil or egg-white, and the splitting up of these substances under the action of ferments releases energy. Hunger is not only a signal of material distress but of low-tide energy: and a meal which restores the balance of fuel also renews vigour.

Food in itself, however, is rarely able to sustain the output of energy due to movement, heat, electrical discharge and other causes of loss. Fuel is effective in proportion to the

draught of the grate. The oxidation of the carbon, oil or acetylene needs a current of air, and if we are to obtain an output of heat, of motor, and of electrical energy from an animal we must supply it not only with food but with air. A draught is needed for the living body as well as for the coal-fire. Breathing is the means by which the draught is set up and carried to all the microscopical furnaces of the body.

The essential element in the breath inhaled either directly from the air or indirectly from air dissolved in water (as in gill-breathing creatures) is oxygen, exactly as it is oxygen which allows coal or wood to flame. The wood or coal is a mass of material in which sun-energy is locked up or banked up and stored. One condition under which it can be made to give out that energy in the form of tangible heat is that the carbon shall be made to unite with the oxygen of the atmosphere; but we may leave a lump of coal in a constant draught for years and no fire will occur. Imagine, however, the coal to be powdered into fine coal dust and to be placed in a mine that is under changing conditions of moisture and of heat. There is then the possibility of combination between the dust and the oxygen or gas of the mine: an explosion may occur with the liberation of a vast quantity of destructive energy—heat, light and force.

The oxygen is not in itself a source of this energy, but when combined with carbon it gives rise to compounds which contain energy, and when conditions occur under which the energy is set free, the potential energy of combination becomes the actual energy of explosion. The air of the mine becomes charged with carbon dioxide, carbon monoxide, or both.

There is a sense in which all muscular contractions are explosions. The carbon of the food, disseminated through the body by the blood, is carried to the muscles for the repair of their material. The oxygen of the lungs is also disseminated by the same blood to the muscles. Here, in accordance with the banking practice of the body, it is stored in reserve, and from this reserve there is given out, every time a contraction or movement occurs, a cheque of oxygen. These combining with the muscle-matter cause an explosion or series of explosions which are usually inaudible. Under some great mental disturbance, however, a contraction of unusual dimensions and energy may be accomplished. The bank may be broken. A vast output of oxygen suddenly combines with whole regiments of muscle-columns and the muscle may be heard to crack. Such an explosion may save a man's life, but it not uncommonly comes near to exhausting him fatally.

Anaërobic Animals.—The primitive breathing mode lies in obtaining means for the energy-production in the body by liberating energy from the food. All animal-foods contain carbon, hydrogen and oxygen; proteid foods contain nitrogen and many other substances. The splitting of the food-compound is effected by a ferment; that is to say, a substance capable of producing far-reaching decomposition without itself undergoing any readily perceptible alteration. Thus diastase, one of the commonest ferments in plants, converts starch into sugar. By this means seeds, spores, many bacteria, many protozoa, eel-worms, even leeches, are able to obtain an amount of energy that suffices for certain manifestations. Such beings are called anaërobic, as they can subsist and move without a supply of atmospheric oxygen.

Aërobic Animals.—Speaking broadly, however, animals and plants need free oxygen and cannot work merely by the decomposition of a complex solid. Whether in other planets beings can utilize oxygen in some extracted form or substitute some other element for their energetics, we know not, but it is at least singular that oxygen is so plentiful in our atmosphere and oceans. Without an oxygen-containing atmosphere so plentiful as our own, there might still be life so long as some oxygen, carbon and nitrogen were

present. Probably, however, the abundance and high development of life on the earth is related directly to the great stores of atmosphere in the rivers and seas, in the porous soil, caverns and subterranean waters as well as in the envelope of the globe. These various atmospheres are not alike; they owe their different compositions in part to gases exhaled by the earth, in part to varying temperature and pressure, and in part to the degree of diffusion of the "normal" atmosphere into the depths of water and of earth.

This atmosphere is to most life highly nutritious, at least in oxygen, but the good in it is hard to assimilate. Air is a mixture of (from one point) good, bad and indifferent things—oxygen, carbonic acid and nitrogen, together with a vast quantity of water-vapour, dust and spores. Water contains dissolved air with all its complications added to those of salt, chlorine and other elements of the ocean. The problem of life-energetics is how to extract this oxygen from the atmosphere and how to combine it with oxidizable material, in order to furnish heat, movement, reserve stores of energy, and growth. Here is a complicated chemical problem which we solve twenty times a minute without consciously performing anything: only when running or walking at high altitudes are we aware

of an effort, and even that is merely the effort of inhaling air. We are absolutely unaware of the means by which the air-mixture is partly robbed of its oxygen, still less of the way in which the extracted oxygen is disseminated, combined, exploded and stored. We know that the atmosphere dissolved in water can only be made to yield up its oxygen to a chemist by treatment, but a fish, insect-larva, snail or coral can extract it without diminishing the pressure or altering the temperature of the water. Moreover, the breathing actions of a man or of an animal are not uniform and mechanical in a simple sense: but are adapted to the varied needs and rhythmical phases of life. Oxygen enough for a sedentary life is not sufficient for a strenuous one, and the respiratory mechanism is plastic, now meeting the demand by simple diffusion and now by secretion or by drawing on the reserve fund in case of a run on the bank caused by climbing, gymnastics or a race for life.

The Respiratory Mechanism.—The respiratory mechanism consists of three parts: (1) The means whereby oxygen is absorbed from the atmosphere, (2) the means by which it is diffused and brought to the various tissues, and (3) the respiratory exchange in the tissues leading to exhalation of carbonic acid and water from the body. The term "respiratory organs"

is usually confined to the first of these parts, and in this restricted sense respiratory organs are either gills, that is, organs for absorbing dissolved atmospheric oxygen, or lungs, by which are meant all means for absorbing oxygen from the atmosphere directly.

Energy Derived from Food.—The need for oxygen varies greatly in different animals and even in the same animal at different times and seasons of its life. The anaërobic bacteria, certain Protozoa, eel-worms and leeches can be kept in an atmosphere deprived of oxygen for a long time without diminution of their vital processes, since, as already explained, these animals have the power of splitting up the reserve food in their bodies and making use of the heat so liberated by the "reducing" changes that give the necessary energy for their movements and life-processes. This goes on so long as new supplies of food are available and on condition that the waste materials, such as carbon dioxide and waste nitrogen, are removed. This may be called respiration by reducing ferments.

Respiration of Cœlenterates.—Above Protozoa we have first the sponges and Cœlenterates (hydroids, medusæ, sea-anemones and corals). With regard to sponges the only process needing much oxygen is that of growth, and it is probable,

though not as yet established, that in this case there is a ferment capable of fixing the oxygen dissolved in the sea, or in fresh water. Currents of water are almost constantly passing through a sponge and it may be that the tissues themselves without any other aid are able both to extract the dissolved air to utilize the oxygen and to discharge the carbonic acid into the outflowing current. Such, at any rate, seems to be the only hypothesis available for explaining the respiration of Cœlenterates. These animals are traversed by an ingoing and an outgoing stream, or by an irregular flow of water in their central cavity. In this case, again, our present knowledge does not allow of a confident statement as to how the dissolved oxygen is fixed. We can, however, say that there are no definite respiratory organs and no diffusing medium until we reach Cœlomic animals. In Acœlomate creatures there is either selective absorption of oxygen directly from the atmosphere dissolved in the water or an oxydasic ferment in the tissues traversed by the water. The larger jelly-fish are in this respect the most needy of the Cœlenterates and require as much oxygen per unit of body weight as does a frog. If kept in incompletely aërated water, these pelagic medusæ shrink to a mere fraction of their former size. Temperature also affects the demand for oxygen,

for as the sea becomes warmer the processes of life, up to a point, go on more quickly and the demand for food and oxygen becomes more insistent.

Evolution of Gills. Mollusca. — In Cœlomate animals we find not only definite respiratory organs but a blood system for diffusing the oxygen, for carrying it to the tissues and for discharging carbonic dioxide and waste matters from them. Beginning with the Mollusca, in which movement is slow, growth slow and egg-production large, we find a variety of gill-like structure produced at different points or along different lines in the several classes. These gills are feathery or plate-like outgrowths of the body-wall and are placed in one or two pairs along the side of the body. As Mollusca, unlike the Acœlomata, do not swallow and exhale currents of water, their gills have to extract the oxygen from water that flows over, instead of inside them. In order to facilitate this flow, the gills are commonly enclosed in a tubular fold of the body-wall so arranged as to permit of water entering at one end and escaping at the other. This fold is termed the mantle and is usually encased in a shelly secretion. Hence by inspection of the shell only, a good deal can be inferred as to the nature of the mollusc that it surrounded. The cap-like shells of *Patella* (the limpet) are related to a circu-

lar series of gill-plumes that almost surround the foot; whereas the ormer-shell with its row of holes, and the slit-like opening of the shell in *Fissurella* allow a definite current to enter the mantle at this point, to bathe the pair of feathery gills that lie at the sides of the neck and to escape at the sides of the foot. The twisted shells of the ordinary marine snails have either a notched or a smooth lip. If notched the shell belongs to a siphonate carnivorous mollusc, for the notch lodges a special tubular outgrowth of the mantle (the siphon) which permits of water being inhaled by such snails just as an elephant draws water with his trunk; but unlike the case of the elephant the water after passing through the siphon bathes the pair of gills and escapes at the margin of the foot. If the shell be smooth lipped, the snail inhabiting it will be vegetarian and without any special means of water supply. The tusk-shell (*Dentalium*) (Fig. 12) is perfectly tubular and in this animal there are no definite gills.

Amongst bivalves the mantle is drawn out in short or long siphons containing extensions of the mantle-cavity. Water is inhaled by ciliary action of the gills (plate-like folds of the body-wall) and enters the lower siphon, passes round and between the gill-filaments and escapes into the upper or exhalent siphon. In burrowing bi-

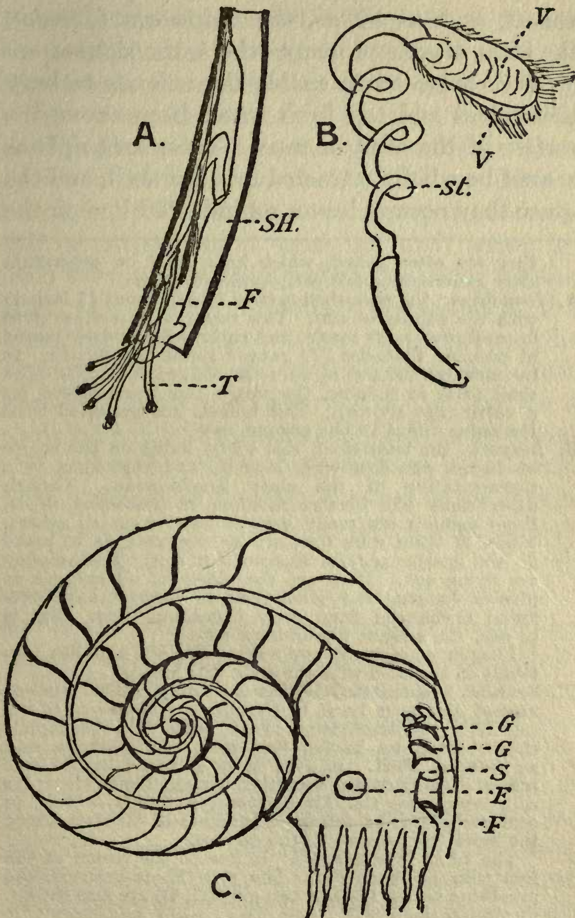

Fig. 12.—Three of the oldest animals, persistent types as

valves, such as *Venus*, the shipworm (*Teredo*), the clam *Mya*, and many others, the siphons are greatly elongated to enable the animals to bury themselves and tap fresh water from above the surface of the sand or mud. These long siphons cannot be wholly retracted into the shell, and the space they occupy leaves an indented line on the

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they are often called, which have lived on generation after generation since early geological time.

A. *Dentalium:* the tusk-shell (actual length about 1½ inches) with the animal *in situ*. This remarkable mollusc lives in sand round our coasts, and gathers its food by means of peculiar tentacles (T) ranged round the mouth. It burrows by the aid of an acorn-shaped foot (F). The shell (SH) is tubular, the upper end being closed by a valve (not shown). This animal has persisted from Devonian times to the present day.

B. *Lingula:* the lamp-shell, still found living on the coasts of Japan, the Sandwich Islands, and elsewhere, is a representative of the class Brachiopoda. Though superficially like bivalve molluscs in possessing shells, these animals are really very isolated from all others. Many of them were formerly so numerous as to make up the greater part of limestone ranges. To-day they are dying out. They are the oldest of all animals at present known, and some such as *Lingula* have persisted unchanged from early Cambrian times, that is to say, the earliest fossiliferous strata.

Lingula consists of two valves (V, V), and lies vertically in the sand with the stalk (St) buried. (× ½.)

C. *Nautilus:* represented as cut vertically. This ancient animal also goes back to Cambrian times, and is the sole living representative of an order of Cephalopods characterized by having four gills, four kidneys, and an external shell. It lives in deep water in the seas round New Britain and the Malay Peninsula. Its congeners were the Ammonites (or Ram's horns), so commonly seen as cottage ornaments in districts where the liassic rocks come to the surface.

The term "Cephalopod" is due to the fusion of the foot with the head (F). The eye (E) is inserted, the breathing siphon (S) and two gills (G, G) are also shown. (½ natural size.)

inner surface of the shell. Thus the habit and shape of the animal can to some extent be inferred from an examination of the dried shell.

Lungs of Mollusca.—The most interesting modification of these molluscan breathing organs occurs in the terrestrial snails and slugs. Nearly all phyla of Cœlomates have managed to establish an outpost, as it were, on land; many indeed have wholly relinquished the water for the land. In all such migrations and colonies, the breathing organs have to be changed from gills to lungs. In a damp, tropical atmosphere, gill-breathing might still be carried out on land for a short time, but if the colonization is to be extensive and cosmopolitan, lungs become a necessity. Such a change of function involves much change of structure. A gill is a delicate outgrowth totally unsuitable to resist desiccation. A lung must be capable of expanding and of contracting, and at the same time of remaining unaffected by the double draught of air that passes through it. Land life demands increased muscular efficiency, as we have seen, not only to support weight, but to push the weight and to overcome the friction of the rocks and soil: and now, with breathing, there comes into the problem a further muscular demand, namely, that for expanding the lung and so drawing in air, and for contracting it and so expelling air. The lung itself is simply the

mantle-cavity—the space in which the gills used to be. The walls, even in aquatic molluscs, are vascular, but they are not rhythmically contractile. Tied as they are to the shell they cannot move. The only thing that can move is the foot—the ventral muscular part of a Mollusc's body. Here, then, is the means of altering the lung's capacity. The foot must be made to elongate and flatten out, so expanding the cavity; and to contract and arch, so diminishing it. The opening of the mantle-cavity must be narrowed to a slit and then the lung can be made effective.

Respiratory Pigments. — The second problem, how to extract and diffuse the oxygen from water-air or atmospheric-air must be noticed. Two methods have been adopted: the use of respiratory pigments and the use of oxidasic ferments. Respiratory pigments are substances that have an affinity for oxygen, somewhat, for instance, as sodium has. They have the power of combining loosely with atmospheric oxygen, so that it can be split off from the pigment without chemical decomposition. Two such pigments are known and both occur in Molluscs. The first—hæmoglobin—confers the colour upon red blood; the second—hæmocyanin—gives blood a blue colour when oxidized. Red blood occurs in very few Molluscs, as indeed the restricted calls upon their oxygen-capacity would lead one to

expect. Hæmocyanin is more commonly present. This pigment is not unlike hæmoglobin, but contains copper in place of iron and has one-fourth its oxygen-holding capacity.

Respiratory Ferments.—The second method of oxygenating the tissues lies in the presence of oxidasic ferments. In some cases (Mussels) these ferments which fix oxygen are attached to pigments, in others they are uncoloured. One peculiarity of Mollusca must be noticed, which is that of a means of banking a reserve of gases upon which the body can draw at times of scarcity. In the highest Molluscs—nautilus, cuttlefish and their allies—the process of respiration is forcible, corresponding to the great muscular exertion and great size of these creatures. Moreover, some of them descend to great depths and in doing so experience rapid changes of pressure, which are reversed on rising again towards the surface. The blood tends at such times to part with its contained gases, and if the gas can be collected its oxygen might be available for subsequent contraction. Nautilus has a vascular gland by which the gases are exhaled and collect in the shell, but, so far as is known, their use is rather hydrostatic than respiratory (Fig. 12).

Respiration of Annelids.—The two great phyla of animals with segmented appendages—the Annelids and the Arthropods—have means of

respiration that vary according to their habitat. In aquatic Annelids the blood is either red or green, the green colour being due to a pigment that is very rarely met with in animals. The body-wall is drawn out into the form of tufts or external gills, a pair of which occur on each segment or a cluster may be developed at the head-end or the tail-end. The tubicolous Annelids have a superb coronal, a spiral outgrowth bordered by cilia, down which a current of water is constantly proceeding to the mouth, aerating the branchial coronal on its way, and combining, as is frequently the case, the function of respiration with that of alimentation. In many of the fresh-water Annelids a current of water is drawn into the food canal through the aboral opening and probably serves as an accessory respiratory stream. In earth-worms the highly vascular body-wall, kept constantly moist by its own mucous investment and by contact with damp soil and air, is the most efficient means of extracting oxygen from the air around it. In all these Annelids the red blood has the same pigment as our own and has similar properties of combining with oxygen, yielding it to the tissues and of returning to the skin laden with carbon dioxide.

Air-breathing Arthropods.—Among Arthropods two very distinct types of respiratory organs are found among the terrestrial and the aquatic

orders respectively. The first are known as tracheæ and consist of branched tubes starting from a common hollow stem which, in turn, opens to the exterior through the body-wall. These tracheæ occur in pairs and are present in most of the body segments. The openings or "spiracles" are provided with muscles and the whole mechanism is adapted for the inspiration of air and the expiration of carbonic acid. The body of an insect readily shows rhythmical breathing movements by which the tracheæ are alternately compressed and expanded, but the branches of the system are so extremely fine that mere muscular pressure will not explain how the air moves along them, and the mechanism of respiration by means of tracheæ is still far from being understood. At intervals the tracheæ are (especially in winged insects) enormously enlarged to form air-sacs and air-cushions. These no doubt lighten the body, but they probably serve another purpose, namely, to provide a reservoir of air from which the fine branches are filled by diffusion and into which the carbon dioxide is discharged.

There is one great characteristic of the mode of breathing in tracheate Arthropoda (that is, the sub-division including Myriapoda, Insects, Spiders and their allies, and the strange archaic Peripatus). It consists in the diffusion of air by ramifications of the tracheæ instead of by blood-

vessels. The blood system is poorly developed and probably serves merely for the absorption and diffusion of the food. In a few insect-larvæ, however (such as the "blood-worm" or larva of the gnat *Chironomus*), red blood is present and serves to extract oxygen from the stagnant water in which these gnats pass their earlier stages of development. In no adult insect, however, is there a circulation of oxygen by the blood. This invasion of the tissues by multitudinous branching tubes permits of a thorough aeration; provides energy for sustained muscular efforts; supplies (through the consequent oxidations of the tissues) a certain advantageous degree of heat above that of the surrounding air (as in bees); enables reserve material to absorb energy for the production of eggs in successive clutches; and also to some extent provides a means for exhaling the carbon dioxide produced by oxidation. It is probable that the larval histories of insects will yield many interesting additional facts to the known means of respiration, for many flies which require an ample supply of atmosphere when winged, pass their larval life in surroundings that are almost without oxygen; for example, as parasites in the stomach of the horse (*Gastrophila Equi*), in wood of trees and the fleshy substance of nuts, galls, etc. Probably in these cases some ferment of a reducing nature is present. An especially inter-

esting modification of insect-structure is seen in the telescopic tail of the rat-tailed larva of *Eristalis*, the drone-fly. This fly, so bee-like as to give rise to the legend of bees arising from oxen or lions (in Samson's riddle "Out of the eater came forth meat and out of the strong came forth sweetness"), lays its eggs in shallow pools of water or of putrescent matter. The larvæ hatched from these eggs have a tracheal system which opens by a tail-tube to the atmosphere. This tube is telescopic and can be extended to a distance of several inches. By this means the larvæ ensure a supply of air in case of rain or of drought.

Gill-breathing Arthropods.—Turning now to the branchiate Arthropods we find Crustacea breathing almost entirely by plate-like or plumose outgrowths of the legs. In the lower Crustacea these legs are all or nearly all alike and are paddle-like structures, similar in form to a palmate leaf, and may number seven pairs or seventy. In higher Crustacea the plate-like gills are confined to the limbs of the middle body-section or thorax. In all cases, however, the gills consist essentially of one or more lobes placed on the inner side of the swimming or walking limbs. Blood, propelled by the heart, wanders into spaces in these lobes and here lies separated from the surrounding water by a mere film of tissue. This blood is colourless, not red, green or blue, as

in Annelids and Molluscs. Sometimes a faint blue tinge is observable, and it is known that

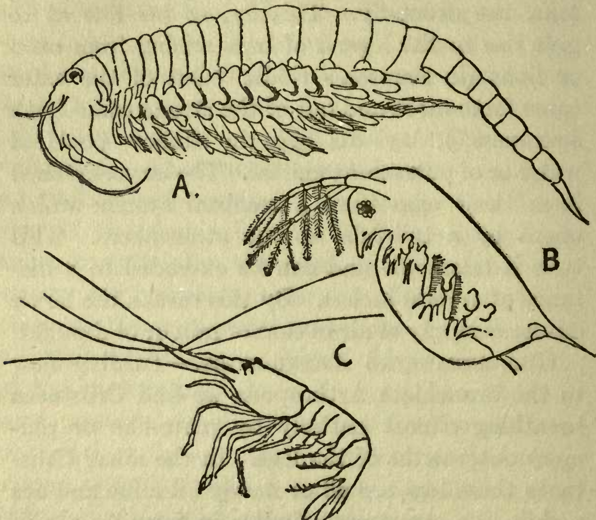


Fig 13.—Group of Crustacea.

A. Fairy Shrimp (*Chirocephalus diaphanus*): found in a few isolated fresh-water ponds in England, and more abundantly in Europe, Asia, and America. The animal lies on its back on the surface of the water, and rows itself along by paddling movements of the limbs. These movements produce a wave of motion passing from before backwards.

This crustacean belongs to the group Phyllopoda, so called from the leaf-like character of the feet. (× 1.)

B. *Daphnia:* a common fresh-water shrimp or water flea; also belonging to the Phyllopoda. The body is enclosed in a shell, from which the two great antennæ, or rowing organs, project in front over the compound eye. (× 30.)

C. *Pandalus:* one of the common marine prawns belonging to the higher group of Crustacea—the Carida, or true shrimps. (× 1.)

many Crustacea have the same copper-containing substance—Hæmocyanin—that occurs in cuttle-fish. Either by the combining power of this pigment or possibly by some more subtle process of absorption, oxygen is extracted from the water and taken into the blood; at the same time some carbonic acid is probably discharged.

In most Crustacea the gills, like those of Molluscs, are enclosed in folds of the body-wall in order to ensure a more definite current of water and more thorough aeration. This device has a nutritive value also, as the lower members of the class, such as *Daphnia*, are thereby enabled to sweep particles of food into the mouth. These folds, or carapace as they are collectively termed, may box in the body just as a bivalve shell encloses a mussel. Such little bivalve Crustacea are extremely common and constitute one of the most efficient scavenging class of aquatic animals.

In the larger and more complex Crustacea, simple casual movements of the limbs are not enough to ensure a sufficient supply of oxygen for the gills; and to amend this, the gills are moved to the base of the leg or on to the body and are then bathed by a constant respiratory current which is carried out by the rhythmical and unceasing vibration of one of the anterior limbs (the second maxillæ). The gill chamber is so arranged as to communicate by two narrow

openings, and as fast as the water is baled out by the anterior slit, a fresh supply is inhaled through the posterior one which lies behind the last leg in prawns and in front of the first in crabs. The modifications of this arrangement are of great interest. Burrowing crabs, sunk in the sea-sand,

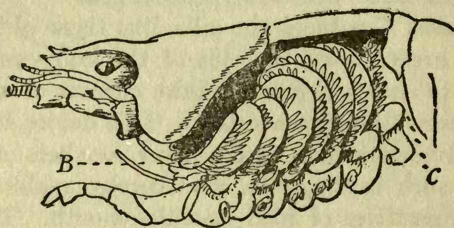


Fig. 14.—Anterior half of the body of a Crayfish seen from the left side, with the carapace or body shield removed to show the gills. The legs have been cut off short. (× 2.)

The gills are seen lying one over another, and in front of the first gill is the baler (B), which in life is constantly baling water out through the aperture just above the reference line. Fresh water flows in at C. The chamber in which the gills are lying is a space enclosed by a fold of the body-wall, and not actually inside the body.

would obviously soon block their inhalent opening with grit if they employed this method exclusively. Hence *Corystes*, the masked crab, for example, apposes the first pair of long, hairy antennæ, thus forming a tube long enough to reach up to the top of the burrow. The baling appendage now reverses its usual action and

draws water free from sand down the antennal tube and into the anterior slit. When, however, *Corystes* leaves its burrow it can employ the normal respiratory current. In some prawns and crabs this reversal of the direction of the current is a usual occurrence, but its significance is not fully appreciated.

Land-Crabs.—An interesting modification of the breathing apparatus occurs in some land-crabs. In warm moist climates and even along the Mediterranean, many crabs have betaken themselves to a terrestrial life, some living just above high-water mark, others right inland, and some modified hermit-crabs have even the power of climbing trees in search of cocoanuts. In most of these crabs the gills are retained, and sufficient moisture is left in the tightly-closed gill-chambers to prevent the desiccation of these delicate organs; such crabs, however, repair periodically to the sea to renew their supply of water or to spawn. Some others, notably the coco- or robber-crab (*Birgus*), whilst retaining the gills in a reduced form have converted the greater part of the gill-chamber into a lung, the walls of which are vascular and enable the robber-crab to breathe air directly, and so to remain for months away from water; in fact, only the breeding season necessitates a return.

Respiration in Vertebrates.—Passing on

now to the vertebrate animals, we have the broad distinction between fish with gills and other vertebrates with lungs. The sharpness of the distinction is, however, lessened by the peculiar breathing organs of the Amphibia, and of certain fish. Gill-breathing, nevertheless, is absolutely unknown in reptiles, birds and mammals at any stage or era. This is one of the many indications that show how marked is the change between fish and amphibia on the one hand, and the three higher groups on the other.

Gills of Fish.—The gills of the fish are composed of bright red tassels set on hoops that encircle the throat, and are usually covered by a movable flap—the gill-cover. Under this flap, the neck of the fish is perforated by a certain number of crescentic slits. Between the slits, the substance of the neck is strengthened by gill-arches, girdles of gristle or of bone to which muscles are attached so that the gill-slits may be opened or closed at will. In all cartilaginous fish (sharks, rays, dogfish) the slits open, independently, to the exterior and are not covered by a gill-flap. In bony fish the gill cover is present, and its rise and fall is regulated by special nerves and muscles. In both cases the blood-vessels that encircle the neck break up into tufts on the surface of the

arches, so that each slit is bordered by two such series of tufts.

The gill-apparatus is set in action by the following mechanism. The throat of the fish is distended by the contraction of the muscles that start from the stiff ventral ends of the gill-arches, and as the mouth opens whilst the gill-cover is kept shut, a gulp of water is taken in ; the mouth is then closed, the throat muscles rise, diminishing the size of the branchial cavity and so force the water out through the gill-slits and under the gill-cover. Thus there is a rhythmical inhaling of water which passes through the mouth, over the gills and out behind them. During its passage over the thin vascular tassels, the oxygen of the dissolved air is absorbed by the hæmoglobin of the red blood and is carried away to supply the brain, muscles, and body generally : at the same time carbon dioxide is exhaled with the outgoing stream.

As in the case of all animal adaptations, breathing in such a large class as fishes is no mere mechanical and uniform arrangement, and the above scheme is modified to adapt various orders for their varied modes of life, and is even altered at different epochs of the life of an individual. For example, a skate rests on the sea-bottom and cannot inhale water through its mouth without swallowing

also quantities of débris, hence it uses a pair of large, rhythmically-contractile openings which lie on its upper surface just behind the eyes. Through these "spiracles" the water opens and passes over the gills. Even the escapement action of the gill-cover is nicely adapted for different orders of fish. In pelagic orders the current is directed backwards so as to aid the forward dart of these active animals—very much, but in reversed direction, as the puff of the exhalent current sends a cuttlefish shooting backwards. Sedentary fish, on the other hand, discharge their gill-water downwards so as to lift them slightly; and any one who has examined fish in captivity will notice the variable extent of the breathing movements. In winter, dogfish, and probably others, breathe at half the summer rate; sticklebacks when mating breathe very rapidly.

Air-Breathing Fish.—Perhaps the most interesting feature of respiration in fish is the adaptation occurring in several unrelated families to permit of breathing air directly or to allow of migrations over land. The common loach sucks down air as well as water, and many North American fish, the gar-pike, the bowfin, as well as the *Polypterus* of the upper Nile and other African rivers, constantly rise to the surface, not only to snatch food, but to inhale air

which passes down their throats. In the family of Siluroids, to which the cat-fish belong, there are many genera which possess special chambers, in which air so inhaled can be stored, and in the wholly unrelated climbing perch (*Anabas*) of the East there is a complicated folding of the gill-cavity. Whether this additional supply of air, over and above that dissolved in the water that flows round the gills, is needed to supplement the lack of oxygen in the water, is a doubtful point. The interest of the habit lies in its bearing on the way in which animals came to leave water and to breathe air.

We have seen that such emancipated Molluscs and Crustacea converted their branchial cavities into a lung, and there are many indications of the same change of habit and function in fish. A common Egyptian siluroid, for example, leaves the lake Kurun (which lies to the west of the Nile, on the borders of the Libyan desert) at night and travels over the damp grass, returning before morning from its nocturnal excursion. The springing goby, *Periophthalmus*, so common on the mangrove swamps of East Africa and Malay, never becomes wholly submerged, but roams over the muddy flats above the sea-margin, keeping its tail in water when at rest. The climbing perch just referred to walks up trees by the aid of its ven-

tral spines, and is enabled to do so by providing itself with a supply of water, or air and water, in its peculiar pharyngeal fold. Young eels (elvers) annually make their way from the rivers overland into tracts of water not directly communicating with the sea. But no fish that we are aware of has adapted itself to terrestrial life in a permanent fashion.

The Air- or Swim-Bladder.—We must now briefly consider the air-bladder, which is related in an important way to respiration. With a few exceptions (of which the gristly fish, flat fish, and the common mackerel are the most remarkable) all fish possess a bladder under the backbone. In a herring, for example, the air-bladder appears as a silvery tube extending from the gills in front to the hinder part of the body-cavity. Careful examination shows that it opens to the stomach by a duct of considerable thickness, which perforates the bladder at about the middle of its length. Such a fish is able to pass air into its bladder or to allow of the escape of the gases contained in it. The surprising fact, however, about the air-bladder, is that it does not contain air. The gas in the case of marine fish contains more oxygen with traces of carbon and less nitrogen. The air-bladder is a gas-cylinder into which the oxygen is secreted from certain arterial

blood-vessels, and may possibly be carried away by certain vessels for the aeration of the body. A certain amount of air, gulped in by the fish, does probably enter the bladder by the pneumatic duct or passage from the food-canal, but this air only serves to dilute the oxygen which is extracted from the arteries of the bladder. In all fish the air-duct is present in early life, as it is the stalk of the process whereby the bladder has grown out of the alimentary canal; but in many, perhaps in the majority, the duct closes up and disappears. In such cases the gases of the bladder enter and leave it exclusively by the blood-vessels.

From this point of view, therefore, the air-bladder is another example of the banking or reserve principle so abundantly illustrated in animal life. It represents a reserve of oxygen upon which the body may draw for its special needs. Just as each animal banks its reserve of food in some chamber (either as fat or starchy substances in the skin and liver), and only utilizes a working supply, or, again, as animals employ only a portion of the oxygen stored up in their muscles, so it seems that fish only abstract small quantities of their central store of oxygen.

Respiratory Pigments in Fish. — The principle, however, goes further than this, for

most powerful and pelagic fish have still another means of storing oxygen and of rendering their muscles capable of prolonged and untiring work. The red colour of salmon, the dark brown colour of mackerel, and the dark red tint of tunny are due to a form of hæmoglobin stored in the muscle itself. Such fish are eminently free and far wandering. Unlike the flat-fish, which rest long hours in one position, unlike even the cod and haddock which, though constantly moving, are not great travellers, the dark-fleshed pelagic fish pursue their prey actively and migrate, in some cases, far up stream to spawn, and down to the deep sea to feed. Dark muscular colour is a sign of greater powers of endurance, of exertion, and of production, and is seen not only in pelagic fish, but in the most strenuous muscles of Molluscs, of Annelids, of insects and birds and mammals.

Respiration in Amphibia.—With regard to the breathing of Amphibia a few words must suffice. The variety of mechanism is one striking feature. Lungs opening by a glottis into the throat are the most usual means of obtaining air. The surface skin and interior of the mouth, however, in many cases act as a diffused gill. External gills are present on the neck of a few primitive newts (Fig. 10).

In all Amphibia the long periods of immobility, and the deliberateness of movement point to a lack of oxygen and to imperfectly developed muscles. The second feature in amphibious breathing is the absence of that gulping of water so characteristic of fish. Only in the early life of one division is such a habit practised, and here it is associated with the presence of true gills and gill-slits on the sides of the neck. By such means the tadpoles of most frogs and toads obtain their supply of oxygen ; but in no grown-up Amphibian does it occur. Further, no swim-bladder, as such, is found in Amphibia, but the statement only shows how names may blind us to the truth of facts. If we call an outgrowth of the throat, lungs and windpipe in one animal, and if we describe it as air-bladder in another, we may miss the connection between the two. The fact is that there is a very close resemblance between these organs, especially when the swim-bladder of the Nile-fish, *Polypterus,* and that of the Mudfish of Queensland are considered. Physiologically at least the lungs of Amphibia and the swim-bladder of such fish behave very much alike. But there is a wide difference between the lung of a frog filled with air during the summer and unused during the winter, and the swim-bladder of an active fish filled frequently with almost

pure oxygen. The difference in behavior is a measure of the diverse quantities of energy-giving oxygen in the two cases.

Reptiles have not improved much upon the Amphibian lungs. They have lost the power of breathing through the skin, and all traces of gill-breathing have vanished from their life-history. Probably the extinct flying reptiles had a better respiratory system than the modern ones. Again, we see that slowness of lung-action corresponds to slowness of movement or to spasmodic quick actions.

Respiration in Birds. — Birds, on the other hand, are the most strenuous and active of all things, putting not only energy into flight, hopping, singing, nesting and preening, but into clutches of eggs. We should therefore expect to find some improvement on the reptilian lungs, and we do find it. The lungs of birds are small and the air-chambers relatively limited as compared, for example, with mammals of about the same size ; but air is drawn not only into the air-recesses of the lungs, but right through the lungs into great air-sacs like those of flying insects. These sacs, unknown in mammals (if we except the vocal sacs of howling monkeys and of some other apes), lie like air-cushions under and between the viscera, and extend in many birds into the skin and

bones. When a bird expands its chest and body, air rushes through the lungs into these sacs and draws with it a great draught into the breathing spaces (*alveoli*) of the lungs themselves. The air-sacs, however, have no blood-vessels, and do not breathe air. When the body contracts the sacs are compressed and their contained air is driven out as a rushing wind, which sweeps out through the lungs, carrying with it the carbon dioxide and water-vapour that has been exhaled. Thus the lungs of a bird are wholly tidal and the air-sacs, while contributing nothing to the direct aeration of the blood, indirectly determine that all the effective part of the lungs shall be completely filled and completely emptied each successive moment.

Muscle Pigments. — Strange to say, birds, unlike fish, have no large oxygen reservoir, at least none has yet been found: but nearly all birds have in their dark-coloured muscles a pigment which acts like that of pelagic fish as a store of oxygen, and enables them to move constantly and to continue forcible movements without undue fatigue. The unusual fatigue and powerlessness of migrant birds seen, for example, at Heligoland, at sea and on arrival from a distant country, is probably due to lack of food and to cold rather than to muscular fatigue simply.

Lungs of Mammals.—Mammals, lastly, have lungs that fit them for the deliberate and yet untiring movements so characteristic of their order. Their lungs are not swept by tides of air. The upper section alone receives and discharges air with each rise and falling of the chest, the greater part of their capacity being filled with stationary air which, in reality, is diffusing slowly both upwards and downwards; the lungs are therefore like a room in which air is constantly changing at the ventilators and more slowly diffusing at the centre.

Fortunately, however, we have still a reserve supply of oxygen upon which we draw with every forced movement. Deliberate people use the air (or rather part of its oxygen content) that diffuses through the lungs, as we all do in sleep and when at rest. Directly we run, however, and possibly even under the mere influence of excitement without activity, our lungs take on a new mode of breathing that adapts them to the enhanced hunger for oxygen. As Haldane has shown, they now secrete oxygen, and breathing proceeds as it does in a fish. Again, the profound adaptiveness and reserve of nature is strikingly exhibited.

CHAPTER V

THE COLOURS OF ANIMALS

The tints and colorations of animals belong to that attractive class of displays which interest the most as well as the least scientific observer.

The interest of colour, like that of form and of movement, is an æsthetic one, and a peacock's tail or a tiger's skin appeals to and satisfies our sense of beauty without raising awkward problems of why and wherefore. Much in nature so far outdistances utility as to discredit the principle of explanation in the minds of many whose voice would be heard appealing against explanation as diminishing rather than increasing their enjoyment in life. The fear and the protest are really needless. There is at present no sign that we can explain anything. What is gained by considering colour and not merely gazing at it, is appreciation of the professional standpoint; we begin to see how to observe. Meaning and plan unnoticed before begin to interest us. We wonder more and are astonished less.

A broad survey of animal as of vegetable life discovers the prevalence of coloration. Man himself is almost the only pallid thing, and baldness or pallor is one of the least natural products

of civilization. The wonder of savages at their first introduction to white men is really the most natural and justifiable of sensations; and the discarding of wigs shows a decided lack in one's sense of the fitness of things. In this matter, as in so many others, women have the right intuition. If animals lack colour or become white (two very different things) they generally lie or move against such a background as to be inconspicuous. The transparent Protozoan and Medusa lie invisible in water, the white hare and arctic fox move across expanses of snow.

The colouring of animals is due to two, physically, very different causes. White and metallic colours, tints that change with one's point of view, mother-of-pearl tints, are due to the structure of the surface of the body, that is, to fine particles or to thin plates. The colour may be seen best against a dark ground, and for this purpose underlying pigment may be present but such colours do not arise from pigments. On the other hand, there is the much larger class of colour effects which are due to pigments. It is to these absorption-colours that the following remarks apply.

Two Classes of Pigments.—Animal pigments are, speaking generally, of two classes differentiated by their nature and especially by

their varied solubility. The most abundant class is that including the brown, grey, chocolate, yellow and red tints of the higher animals. The colours of hair are in fact as well as in name a convenient summary of such pigments. Wild animals are generally only hair-coloured, that is, their skin is usually pale and all the pigment is present in the hair, feathers and eyes. A few, however, have both skin and hair coloured. Loss of hair as in whales, elephants, rhinoceros and man is accompanied by a special development of brown or grey pigment in the skin.

Hair-Colouring of Wild Animals.—The most general fact about such hair-colouring is its uniform tone. Leaving aside domesticated races and considering wild mammals and birds we are struck by the general brown and grey tint or dun tint. Rats, mice, rabbits, foxes, shrews, otters, wild horses, wild sheep, wild dogs, wild cats, monkeys, bears, lions, most deer and many others, are of this monotone character. Exceptions there are, of course, in the form of tigers, zebras, some antelopes and civets, but these fade into insignificance when compared with the vast numbers of the monotonous animals.

Secondly, the monotone is really misleading and due to combinations of different colours in each individual hair. A grey rat or rabbit, for instance, is actually parti-coloured, but the pig-

ments are so closely blended as to produce a general grey effect. Examination of such hair under the microscope shows that the grey pigment is not uniformly grey, but is irregularly distributed and alternates with white or brown. The coat, in fact, is of many colours.

The Shading of Animals.—Thirdly, in such wild animals a scheme of colouring exists and is such that the upper surfaces of the body and limbs are usually darker in hue than their under surfaces. A dark back and a pale breast is the most general of all schemes. This contrast is better marked in short-legged than in long-legged animals, for a reason that becomes clear when the relations of light and shadow to animal coloration are considered. Here it will be sufficient to consider shadow. Shadow throws up an object and renders it conspicouus. If by toning the back dark and the breast light, the shadow of the upper part just balances the dark tone, the effect of contrast will be lessened and the animal will no longer be so apparent. The principle can even be applied to individual parts of the body; a projecting brow or flank can be painted out, as it were, by lightening the hair just beneath it. Such marks, therefore, as are seen on many antelopes are not real contrast-colours, but are efforts to efface parts, which if coloured uniformly, would stand out boldly.

The meaning of other bars and stripes is, however, more complicated.

Alteration of Colouring by Domestication.—The effect of domestication upon animals is to alter completely these rules of natural coloration. Domesticated races may be monotones, but the uniformity is real and not a coat of many colours blending into one. More commonly they are spotted or blotched in a bold manner that is unknown among their wild ancestors. The wild cat of Egypt is yellow, of Great Britain grey and faintly striped, but the domestic cat is anything from black to white through a vast gamut of colours and patterns. The wild dog was probably grey like the wolf or red like the Indian Cyon, but the modern breeds are either true monotones or spotted. The wild cattle of Europe were probably brown, the wild horse of Asia is dun, whereas the modern cattle are blotched or true monotones, and horses are frequently spotted with a curious livery colour. The wild boar was a grey of the true speckly, mixed tint. The modern pig is pink, black, or parti-coloured. The goose is perhaps the only animal that has not changed under domestication. Moreover, the "effacing gradation" of shading from dark above to white below has been abolished by human selection; and we have cattle, dogs and fowls that can be seen

from far in consequence of this lack of chest whiteness.

Coloration of Birds and Reptiles.—We must now consider briefly the nature and arrangement of pigments in birds and reptiles. Their colouring is due to the same class of soluble substances, the so-called "melanins" we have considered, but there is a broad distinction between the colouring of birds and that of mammals. If we look at any large collection we notice a broad distinction between the delicate tracery of the plumage in birds that frequent the ground of moor, meadow and woodland, and the contrasted plumage of the more active perching birds that change their habitat minute by minute. As examples of these compare thrush, snipe, woodcock, nightjar, partridge and waders generally, with tits, swallows, finches. Better still is it to compare the birds in the open and to note the difficulty of seeing "cock" or partridge before flushing them as compared with the way in which ear and eye are drawn to finches and tits by their fussy movements and conspicuous colouring. The speckled, brownish or ashen type of coloration is seen also in reptiles, particularly in snakes and lizards. In fact, speaking generally of animals, those which spend long intervals motionless possess a coloration which reproduces in a more or less conventional manner the play of

light and shadow and the dominant tone of their habitual surroundings. In the case of sedentary birds as the American artist, Thayer, has so beautifully shown (p. 256), the "graining" reflects pictures of shadow under foliage with delicate patterns of vegetation drawn across it. The peculiar chain-like patterns of snakes are not understood, and indeed there is still a vast field for discovery in every part of colour-physiology. Because these cases of effacing coloration appeal readily to our sense of fitness, they have been hailed as instances of "protective colouring," and the explanation of one of the most complicated of colour-phenomena is held to be given by "protection" which in animal as in human economics is thought to meet the needs of the time. But when the magnificent range of such harmonies is considered both in animal and plant life, of which colour-harmony is only one, the futility of such a ready-made solution is only too apparent. There is a fitness between animal life and its surroundings. The question remains how close is the fit, and that can never be settled if we remain content with a vague protective phrase.

Function of Dark Pigment.—Before leaving the Reptilia, mention should be made of the meaning of these insoluble pigments to which all the higher animals owe their colouring from the

black of a raven's wing to the grey of a cat's whiskers. We have seen to what uses they may be put and have rapidly glanced at some of the pictures into which they enter. We have now to ask what use they served that has enabled such pigments to be so lavishly employed.

One, perhaps the chief and primary use of these insoluble and variably coloured melanin-pigments is the power of absorbing the ultra-violet rays of sunlight. In tropical and warm-temperate countries, bright light contains a quantity of these penetrating and chemically active rays as well as heat-rays. Fair people rapidly become sunburnt under their action, and the response of the skin in becoming brown is a defensive one, for the pigment does absorb such rays and protects the deeper-lying organs from injury. In fact, the broad classification and distribution of races of mankind show that the light and dark brown races inhabit or have inhabited the hotter regions of the world. The workers in the Indian field are darker than those of the town. The natives of Australia and Africa are darker in the desert regions than in the more temperate zones. On the other hand, light races do not permanently darken when living for generations in the tropics, and the yellow Oriental races have not acquired the negroid tint although in many mongolian countries the

amount of heat is equal to that of India or of Australia. There is, therefore, no simple relation between pigmentation and light-exposure, but nevertheless there is the broad association of dark native colour, with a dry, hot climate.

Now the majority of temperate animals have as we saw (p. 62–64), come from warmer or subtropical countries in the course of ages or are descended from an epoch in which what are now temperate or even arctic countries were then tropical. Hence the persistence of dark colouring in many animals may be due to no more remote reason than conservatism, the tendency of the negro to remain black even in England or America, the ultimate explanation of blackness, so far as we can now see, being protection from ultraviolet light.

Origin of Pigments.—But black pigment (which is really dark brown) is due to a substance which, as every lady knows, can with a little hydrogen peroxide be transformed into brown, red and even yellow. These shades are probably phases of oxidation of a "mother of pigment" when acted upon by some ferment. The older explanation that they were due to waste and altered blood pigment is far less tenable. We have to imagine that every cat, guinea-pig and man is born with a certain amount of this colourless "mother of pigment," this "chrom-

ogen" as it is called. To produce colouring a certain ferment must act upon the chromogen. In the best-known case this ferment is a wide-distributed substance known as "tyrosinase" (found, for instance, in the skin of the guinea-pig).

Some such ferment-action goes on in many plants and animals, and, as has been proved, often takes a part in relation to oxygen and thereby initiating oxydizing changes. When the ferment acts upon the chromogen it produces in the latter first a yellow, then an orange, afterwards a reddish and finally a brown tint, the actual colour being governed probably by the amount of oxidation to which the chromogen is subjected.

Colouring of the Races of Men.—We can now see more clearly the differences and the resemblances between the races of mankind. The white races have chromogen in their skin and hair, but the ferment only in the latter. The yellow races have some of each in the skin, much in the hair. The red Indians have more in both skin and hair and the Negroid races still more in both situations. In domesticated races of animals the distribution of these factors, which together give rise to colour, is frequently, as we have seen (p. 125-6), more irregular or more uniform than in wild races. A fox-terrier, Dutch rabbit, Dalmatian dog and tortoiseshell cat

show that the primitive, small-patterned marbling has given place to a large-patterned chequering, which implies that the chromogen or the ferment is absent from certain areas. The zebras show, however, that the two factors may occur in definite areas in a wild animal. Further inquiry is necessary to determine what brings about this areolation of colour.

Whitening of Hair.—A word on whiteness may fitly close this section. We know that white hair develops periodically in some animals such as the arctic-fox, stoat and Alpine hare; that in man it develops only after maturity and to varying degrees in dark-haired people: and that whilst white feathers occur sporadically in dark garden birds (blackbirds, sparrows, etc.), true albinos are defective animals, often deaf, or with bad teeth and tender eyes. There seem to be good reasons for regarding albinism as a phenomenon perfectly distinct from cases of partial whiteness.

This white colour is due in most instances to the loss of pigment in the hair or feathers, and to the infiltration by air-bubbles of the spaces previously occupied by colouring matter. In few grey wild animals are the hair-shafts free from some air-bubbles, and the problem of arctic whitening is to explain the seasonal loss of pigment. The most feasible solution is that of Metschnikoff.

According to the distinguished director of the Pasteur Institute, this loss of pigment is occasioned by the immigration of colourless blood-cells from the hair-bulb into the hair-shaft, and by the ingestion of the pigment by these phagocytes. Following upon the return of the pigment to the hair-bulb, bubbles of air filter into the spaces so created and the hair becomes grey or white according to the activity of these blood-cells. It is probable, however, that this translocation of pigment is only one, and perhaps not the most frequent, mode of blanching.

Influence of Light on Pigment.—Loss of pigment either periodically or sporadically (as amongst the feathers of otherwise dark plumaged birds) leads naturally to the question of the relation of light and of darkness to the development of pigment. There is a vast river system, subterranean, dark and cold, in the earth's crust. There are vast abysses in the ocean, still, cold, and pressed upon by the weight of superincumbent waters. There is the long arctic and antarctic night when even at noon one cannot see to read: and, lastly, there are habitats chosen by parasites, whether within animal or plant hosts, which are dark. If light is a necessary antecedent to pigment formation we should expect to find cave, abyssal, and parasitic animals unpigmented; and we should not expect to find that

pigment can develop normally in the interior of animals. There is, however, the possibility that whilst light may not be essential to the formation of pigment, yet that the tint of the pigment may be governed or altered by the action of light.

Colouring of Cave-animals.—The most famous subterranean animal is the *Proteus* or blind newt of the Carinthian Grotto. This newt, a foot in length, is perfectly white except for a pair of red gills on its neck. Its eyes have degenerated and are covered with skin. A somewhat similar cave newt, *Typhlomolge*, is known from caves in Texas, and this again is colourless. There is also an interesting fauna of cave Crustacea, and most of these, again, are white and blind. The nearest allies of these white troglodytes are the coloured newts of Europe and America and the coloured keen-eyed *Gammarus* of our fresh-water streams. Hence we are justified in thinking that continued darkness has led to the disappearance of this pigment; and also in associating this blanching with the loss of eyesight. The evidence is, however, not conclusive, since it is possible that the seeing, coloured newts and shrimps, might be those which found their way out of the darkness, and that the blind shrimps and newts are the original stock. The experiment of bringing *Proteus* into the light shows, however, that the opposite series of events has probably

occurred, for the skin of this animal is still sensitive to light and acquires a brown colour upon exposure; it behaves, in fact, somewhat as a very slow, photographic plate. The eyes, however, remain disused and sight is not reacquired. Hence it appears likely that *Proteus* and its American representative, *Typhlomolge,* are descended from seeing, coloured newts, which in the old and new world respectively have been driven by stress of competition into darkness, blindness and pallor.

Colouring of Deep-sea Animals.—Life in darkness, however, does not always involve such degeneration. The abysses of the sea are peopled by a variety of fish, Crustacea, molluscs and other animals. The colours of these are marked and even vivid. The deep-sea fish are either black or brown, the Crustacea are scarlet, the holothurians (allies of the shallow-water form of which the Chinese make their edible product, trepang) are purple or brown, the corals are pink or red. There are, it is true, a certain number of blind races both of fish and of Crustacea, but, on the other hand, there are at least as many which have enlarged eyes, and blind Crustacea occur in the shallow ocean water where light is available even if it be not employed. From the surface of the ocean down to the greatest depths there are coloured, seeing, races of animals.

In explanation of this singular fact, the presence of phosphorescent light in the abysses of the ocean has been adduced, and attempts have been made to show that the depths of the sea are lit up, not, it is true, by the sun (for the visible rays of the sun probably do not extend further than 200 fathoms if so far), but by light given out by corals, fish and Crustacea whose bodies are girt about with little lamps or torches. Just as a glow-worm can extinguish its light so it is thought that these deep-sea animals may exercise some control over their lights. In some cases, perhaps, the luminosity is given out continuously. These phosphorescent organs would at least light up the surface of the animal that bears them and might therefore compensate for the lack of sunlight.

The difficulty of testing and accepting this attractive suggestion lies in our ignorance of what happens in the deep sea. We know that when roughly hauled up in dredge or trawl to the surface, these abyssal animals glow with fire which dies after a while and can be rekindled by agitation, just as sparks of the phosphorescent light are emitted from many shallow-water, marine, and even terrestrial animals; but we do not know how constantly or how intermittently this light is given out when the lantern-bearers are living under normal conditions. It

may be that the lantern-light saves their eyes and their pigments from degeneration. It may be that ultra-violet light from the sun penetrates far deeper into the sea than we imagine. It may be that, as the deep sea is peopled by the migration into it of shallow-water forms, its inhabitants have retained by sheer conservatism the eyes and pigment of formerly insolated generations, modified but not extinguished by the conditions of the abyss.

Recent experiments, however, tend to show that absence of light has in some cases a rapid blinding effect, even in a few generations, upon animals accustomed to live in daylight. After a few generations kept in darkness, the eyes of *Daphnia* are strikingly modified and their pigment becomes altered. The influence of prolonged arctic darkness, as related by explorers, shows how great a part light plays in maintaining health. All internal parasites are colourless, whereas their free-living, sunlit allies are pigmented. On the whole, therefore, we are bound to conclude, though the evidence is not crucial, that absence of light favours the disappearance of pigment. The development of eye-colour in darkness, the formation of black pigment in the dark interior of many animals, warn us, however, not to accept the statement that the formation of pigment is dependent upon light. In our present

knowledge we must say that pigment can arise independently of light, that the melanic pigments are produced by the interaction of a ferment and a colourless chromogen, and that light may determine the colour or tone of a pigment.

Soluble Pigments.—The dark insoluble pigments we have so far considered are especially characteristic of the higher Vertebrates, though not limited to these. They occur also in Amphibia and fish and in certain Annelids; but in these classes the melanic pigments are associated with lipochrome or fatty pigments of an entirely different nature. These colouring matters are much simpler in constitution; in their purest form being a hydrocarbon, but one that readily oxidizes. They occur in four tints, red, yellow, purple, and blue, and have an exceedingly wide distribution both in animals and plants. The "yellow spot" of the human eye, the visual purple of the retina, the yellow yolk of eggs, the orange tint of a carrot, the red of a tomato, are all due to such lipochromes. These pigments are as characteristically soluble in alcohol and essential oils as the melanins are insoluble. Being frequently dissolved in fatty or oily media, these pigments are also found in many reserve products, such as berries, roots or tubers, fungi and eggs. There are many other kinds of colouring matters in animals, but only these two, the mel-

anins and the lipochromes, can be dealt with in this work.

Colour-changes.—We now come to the peculiar phenomena known as change of colour that are exhibited by many lizards, amphibia, fish, crustacea, cuttle-fish, and a few insects. The most striking feature of this manifestation is the property of altering the hue, and even the coloration, of the body in a short period of time, either in a few seconds or at definite periodically-recurring intervals of a few hours. This change of colour differs markedly from the seasonal changes of plumage or pelage, and also from the gradual colour-change in many insect-larvæ when placed on contrasted surroundings. A small cuttlefish such as can be taken with a shrimp net at low tide on our southern sandy bays, exhibits the momentary changes in a most striking manner. At the least agitation its body blushes a reddish brown, and then instantly fades to an intense pallor, followed by another blush. Shrimps and prawns transferred from a dark-bottomed dish of sea-water to a white vessel speedily alter from a sandy or red-lined pattern to a transparent and almost colourless state. Plaice and many other bottom fish have the same property of rapidly altering their tone. Heat and cold, moisture and dryness, softness and roughness call forth similar rapid changes of colour in frogs and some lizards.

Rhythmical Colour-changes.—More significant than these temporary changes of colour are those rhythmically recurring phases that accompany sleep and waking. Many animals sleep by day, others by night. Like flowers, they do not need the awakening touch of nightfall and daybreak in order to quicken their pulse and set them going. Light and darkness have played alternately so long upon their nervous system as to produce a rhythmic habit of action and repose which is helped, but not begun, by daily and nightly recurrence. So the Æsop-prawn *Hippolyte* sleeps on the sea-weed of its choice during the day, even if we plunge it in a dark chamber, nor does it fail to awake at evening though we turn its night into day. Now this "periodicity" is expressed in the colour of the body. The wakeful hours of *Hippolyte* are hours of expansion. The red and yellow pigments flow out in myriads of stars or pigment-cells; and according to the nature of the background, so is the mixture of the pigments compounded to form a close reproduction both of its colour and its pattern; brown on brown weed, green on ulva or eel-grass, red on the red algæ, speckled on the filmy ones. A sweep of a shrimp net detaches a battalion of these sleeping prawns, and if we turn the motley into a dish and give a choice of seaweed, each variety after its kind will select the one with which it

agrees in colour and vanish. At nightfall *Hippolyte*, of whatever colour, changes to a transparent azure blue; its stolidity gives place to a nervous restlessness; at the least tremor it leaps violently and often swims actively from one food-plant to another. This blue fit lasts till daybreak, and is then succeeded by the prawn's diurnal tint. Thus the colour of an animal may express a nervous rhythm.

Such reflection of the inner states by outward show, is seen in many lizards, fish, cuttlefish, and even in some insects. In these sensitive animals, the sleeping state is usually expressed by pallor, the wakeful condition by dark colouring.

Lastly, the question of the importance of pigments to animal life calls for notice. We know that such pigments as we have here dealt with, absorb light, but there are no known processes in animal economy for which light is an essential factor except sight, and we cannot suppose every pigment spot to be a means of distinguishing darkness from light. The analogy of plants suggests that pigments play many parts, that they may render easier some task that is only rarely performed without them, and that they are factors in that refined and intimate associateship between living energetics and inanimate forces of which biology is only beginning to form a conception.

CHAPTER VI

THE SENSES OF ANIMALS

Animate and Inanimate Behaviour.—One great difference between beings and inanimate substances lies in their behaviour. We speak of the reciprocal behaviour of certain substances as a chemical reaction, and are beginning to realize how profoundly conditions may modify that behaviour; how what is true of an experiment carried out with ordinary moist air, may never occur in dry air, or *vice versa;* how impurities such as lithium are in every bit of glass apparatus and may be a condition of a certain result which would never arrive if perfectly pure silica were used; how minute traces of a substance may have a determining effect on the final result. In an organism there are means of detecting, and often of expressing an attitude towards, these conditions of reaction. Above all, there is in a being not only a certain awareness, but a certain power of choice, a certain independence when faced by a multitude of alternatives. The movement of a barometer and of a swallow rise and fall together, but the glass is simply inertly submitting to atmospheric pressure, whilst the bird is aware of a thousand changes: the in-

creased moisture and other conditions of the air, the altered abundance and distribution of insects, and no doubt many other changes of which we have no conception. To put the matter very briefly, the animal is pressed upon (though often not to the point of consciousness) by altering waves of light, heat, degrees of moisture, of gravity, hardness, odours, chemical substances. Some of these waves make no more impression upon it than does the sea on a rock, or the wrong key on a lock; others find a responsive reception. A key has been found that fits some lock and the bolt shoots back. In other words, movement is a response to a particular stimulus. Not only movement, but internal, as well as external, change of any kind is set going by the existence of this exclusive sympathy between the properties of beings and the keys that unlock them. In some animals, as in clocks, only one key sets the movements going; in others, several. In ourselves memory and association are more powerful than actual change of current order in producing an effect.

Under Lock and Key.—The sense organs and the nervous system form together the locks which determine animal behaviour. If we try the keys of light, moisture, odour, or food upon the ear the bolt remains fixed; the right key is the key of sound, and this is again a whole gamut:

some notes too low for us to hear, some too high. To some we remain inert, while others raise passions and win battles. The lower consciousness, roused from its sleep, becomes in turn a key that unlocks our energy. So with animals, the varying play of the complicated inorganic world calls forth in them no chaotic and inconstant changes, but an orderly sequence of responses as definite as the classification into which their structure falls. Behaviour is organized and individualized.

This harmonious result is far beyond a complete analysis. It is often attained by the nervous system acting upon the body under the stimuli of the sense organs. But it is realized in Protozoa, in animals that have no organs of any kind. Adaptive response is, in fact, a quality of living matter, just as much a property as is its complicated chemical composition or its structural cells and nuclei.

The Outer World and the Sensory World.—The outer world, in a magnificent fulness and variety, beats upon all living things, but sensation of that fulness and variety is felt by few. Where there is no central nervous system, reaction can hardly be conscious. Some Protozoa, for example, respond to different rays of light, such as red and green, by a differential movement, but they do not perceive the light as red or green. Many seek their food by responding to the

presence of carbonic acid in the water, for by moving towards that acid they are brought into contact with bacteria upon which they live, but they do not perceive the gas. The *Amœba* selects from a mass of algæ one or two forms upon which it feeds by flowing round them and enclosing them by its mobile body—performing, in fact, the exact opposite of the process in ourselves, for whilst the food passes into us, Amœba gets outside its food. But this constant handling of oval or rectangular algæ gives no sense of form to Amœba. These green cells make no colour-sensation upon it. The cold or heat of the water determines its activity or stillness, but produces no sense of what we call heat or cold. These must be in all animals some inner world unlocked by the keys to which they respond, but it is a world utterly different from that active world of fulness and variety as we know it, and as different from the perceptions which it awakens in us. The unconscious world or state which is unlocked by touch, gas, light, and so on, is only known to us by the responses which animals make. This constitutes their world. Towards all other stimuli or beating of the environment they are utterly unresponsive. These, however few they may be, suffice for their needs. We may call this poverty-stricken collection of sensations the *Sensory world*, so long as we understand by that term, not

perception, but such a dull and unilluminating sense as our own sense of temperature, hunger, or pain.

Responses of Simple Animals.—This sensory world, though absolutely different from the outer one, is so delicately adjusted to the moment and behaviour of animals as to guide them safely in an environment of which they know nothing. The *Paramecium*, or "slipper-animalcule," has three adjustments or threads by which, as it were, it hangs in a treacherous and threatening world of which it realizes nothing.

Medusæ.—The *Rhizostoma* (a medusa) has only one response, namely, to wave-vibration, yet so adequately adjusted are its movements to its needs that the muscular response to waves maintains it in a quiet stratum of water, draws food into its mouth, and aerates its tissues. This response is effected by the little weighted sense-organs that occur at intervals round the bell-margin and communicate with the muscles by the aid, and under the governance, of the nerve-fibres that encircle the margin of the bell. This stimulus transmitted by the sense-clubs from the agitated water is apparently the only key that unlocks this jelly-fish. The sensory world is reduced almost to the point of Nirvana.

Senses of Earth-worms.—The earth-worm

lives a much fuller life. It is the first animal to acquire a sense of form, as Darwin showed by noticing the way in which leaves and paper cut in various shapes were handled by the lips of worms and then drawn into their burrows. Though having no eyes, these animals distinguish readily between light and darkness, reaching out of their burrows by night and withdrawing into them again when day dawns. Heat and cold are stimuli to which appropriate responses are made: warmth causing earth-worms to ascend, cold causing them to descend and so to escape from frost. Intense heat is avoided, like intense cold, by prolonging the burrow to a great depth. Some earth-worms also show a capacity for making unusually violent bounding movements in the effort to escape from moles.

Nervous System of Worms.—The nervous system which facilitates and governs these various responses consists of a double chain of nerve-knots or ganglia placed on the ventral surface, with the exception of the first pair or "brain" which lies above the mouth and innervates the lips. No sense-organs more complex than scattered touch-cells are present, showing that an animal may live a fairly full life without possessing any of the highly organized sense-organs that keep ourselves informed of change in the outer world.

Senses of Arthropods.—The Arthropods and the Molluscs are the typical examples of Invertebrates in which a "brain" is developed. By a "brain" is meant that part of the nervous system in which the sensory world, unlocked by the keys of appropriate nervous stimuli, has its especial seat. It is the nerve centre in which sensations may rise to the point of perceptions, and in which, therefore, consciousness is born. In addition to these properties, the brain possesses in a high degree the oldest property of nervous tissue, namely, the governance of the body along the lines of adaptive muscular response.

Arthropods possess the sense of sight, and even of colour-vision—or at least the property of choosing certain rays of light and of avoiding others. Thus if a spectrum be placed over a long water-trough containing a number of *Daphnia*, the animals will congregate under the green rays. They will move towards a source of light somewhat as a moth makes furiously for a candle. This response, like all the rest, is an adaptive one. *Daphnia* feeds on minute floating algæ which can only grow and multiply in light. Hence by moving towards the source of light *Daphnia* is unlike the moth, making for the likeliest source of food.

This movement is, however, carried out by

Paramecia and most plants, and is therefore independent of eyes or of any sense-organs; but it does not follow that the presence of some form of eye may not be an advantage. The quicker the response, the more rapidly will food be obtained; the more quickly also will the next generation be developed. *Daphnia*, however, like all Arthropods, has two kinds of eyes: a simple eye in the middle of its "forehead," and a pair of compound eyes so nearly fixed together in the middle line as to appear like one; the latter are constantly vibrating. The meaning of these "ocelli," or simple eyes, in addition to the compound eyes has long been a puzzle to naturalists. These two contrasted types of eye-like structure occur in all crustacea, insects, Arachnids (that is, spiders, scorpions, king-crabs, and mites) and millipedes. Nor does the puzzle end there, for all vertebrates, even man himself, have, in addition to the paired functional eyes, a cone-shaped body—the pineal body—which acquires in some fish and lizards an eye-like structure. This so-called pineal eye is closely attached at one end to the brain and underlies a little clear scale on the roof of the head. The function of this third "eye" is at present unknown.

Sight in Arthropods.—Coming back to *Daphnia* and its allies, the development of the paired compound eyes in Arthropods, espe-

cially in insects, is carried to a high degree of complexity. Photographs taken through the eye of a dragon-fly show that, though the eye is compounded of many lenses and sensitive areas (retinulæ) corresponding to them, yet the whole eye throws one image on to the retina. However complex such an eye may be, it is devoid of any focussing arrangement and can only receive a clear image when the retina and the object are separated by the focal length of the lenses. Hence the need for active movement on the part of such eye-bearers. Either they must move their eyes to and fro or (by far the more common plan) search actively. The incessant and fussy activity of insects thus receives some explanation. But when the image, say of some flower is clearly defined upon a bee's eye we have no right to think that it means to the bee what it does to us, for we know that we interpret sight by touch. An insect's clear sight is limited by a few inches or feet, and its interpretation of the images gained at that effective distance is probably in proportion to its tactile sensations. These touch-sensations are probably very acute and take a far larger share in the inner, or sensory, world of Arthropods than in our own, though whether they rise to the threshold of consciousness as perceptions seems at least doubtful. Colour appreciation is a vexed

question, but there certainly seems a relation between the colours of flowers and the attraction that they have for bees. Movement of an object across the field of sight instantly arouses insect activity, and even a shadow falling upon a resting butterfly startles it at once.

Smell in Arthropods.—The sense of smell is also very acute in insects, and probably in Arthropods generally. Thus ants of a given colony have each their nest-smell by which they recognize one another and distinguish and harass exactly similar fellows from a neighbouring nest which are tarred by a different brush. Moths and butterflies mate by means of this sense. The male in many species is provided with beautifully plumose antennæ covered with hundreds of olfactory hairs. These hairs are in close association with the "brain" by a system of nerves, and the brain in turn controls the muscles of flight. The female of such insects has no such special endowments, and may even be deprived of wings and wing muscles, but she has a special odour-producing gland near the tip of the tail, and the faint scent from this gland (to which it need hardly be said we are utterly impervious, so unresponsive is our nose to myriads of impressions that lower animals receive and respond to with ease) is carried by damp gentle breezes over the countryside in an extremely attenuated

form. Yet in this almost incredibly diluted state the scent of the oak-eggar moth or of the vapourer is not imperceptible, and if there is a male in the district he will soon be found by exposing a female on a mild damp evening. This art is called "sembling" (assembling) and is a commonplace of entomological procedure.

Sense of Locality.—Such fineness of sensation suggests that many insects carry out their responses to a degree of delicacy unknown to us. A bee or a wasp circles round the neighbourhood of her nest and seems to fix the situation of each object in her "memory" so that she can find her way back again with ease. Even if the nest be moved from the starting-point of her morning flight she will return to the exact spot and appear surprised to find it gone. Probably our world of perception, and still more that other world of conception, is too much with us to allow us to print sensation upon our memory as does a bee or a wasp.

The Perceptual World.—At what point in animal organization does this world become real? What degree of refinement of sensation, or what multiplicity of sensation, creates the faculty for perceiving the outer world? What still greater civilization is necessary before constructions can take place in the perceptual mind and a new, wild world of conception arise

within? A few suggestions are all that can be given in this work in reference to such far-reaching questions.

Conditions for Perception.—With regard to perception: high quality as well as the quantity of the nervous system, and, probably, especially of that part which we call brain, is an essential preliminary. One important factor in determining this result is the reaction of the body itself upon the nervous system. We are too apt to think of sensation as dependent only upon a certain stimulus set up in nerves by change of environment, and we forget too readily that the effect of this stimulus depends, not only upon the external world, but upon the receptiveness of the nerves. In sleep, noises, odours, even "pains" fail or may fail to wake us—that is, they fall upon our nerves in an unreceptive mood. Thinking over this "moodiness" of living beings, we suddenly see that from plants right up to the highest animals, periods of nervous receptiveness and of dulness recur. Night and day, as we have seen, are often accompanied by alternative phases of activity and repose. Winter and summer on land and in water are again periods of rest and responsiveness. These rhythmic alternations set up a rhythm in the nervous system to some extent independent of the external world. Not only is a sort of memory thus es-

tablished, but the body itself reacts upon the nervous system at certain periods. Many children only develop late; they need some stimulus which has to proceed from their glands and muscles and has to act upon the nervous system before this becomes fully receptive. Some children are temporarily, some remain permanently "feeble-minded"; there is an arrest of development in such cases; perception there may be, conception is limited and difficult. In curable cases an extract of a gland in which these subjects are deficient in quality, and often in quantity, may do good. The blood and the nerves respectively carry from the body to the central nervous system, material and impulse which assist growth, create "tone," and pave the way for further fineness of sensation and of perception.

It is probably to these unconscious impulses, rhythmic or unperiodic, which flow from the body to the nervous system, that the perceptiveness of the brain owes most. "Sensations" of sound, sight, smell, and so on, may occur without consciousness being aroused; we are still in the sensory world. This is probably the case with all invertebrates save the higher arthropods and cuttle-fish. But even these imperceptive animals are subject both to the action of the outer world and to the reaction of their own

muscles and organs upon their nervous system. These stimuli from without and from within play constantly or rhythmically upon the nervous system and form the basis upon which perception is founded. Perception is a new world, but it is unlocked by the same keys as those which admit to the sensory world.

THE CONCEPTUAL WORLD.—Little as we know of the conditions of perceiving the outer world, we know still less of the means by which we build up our perceptions with a new constructive synthesis and call them conceptions. Yet here is the world in which we are at home. Our senses are less acute than those of most animals and we are often deprived of one or more of them from or soon after birth. Our perceptions may therefore be far less extensive than those of the higher animals in which they are stored by the quest for food, the avoidance of enemies, and the manifold rain of impulses. Yet under all these disadvantages we learn and make our conceptions quickly, and are ruled by them all our lives. Unconscious of perceptions, often blinded by our "notions" to the form and even the existence of things about us, we make our own world—often, indeed, are not happy until we live in an artificial world of our own construction. Perhaps a dog chewing the cud of the day's reflections is lifted up into a conceptual

world founded on olfactory experiences and dreams of smells.

CHAPTER VII

SOCIETIES AND ASSOCIATIONS: SYMBIOSIS

THE study of animal life is apt to take the standpoint of the individual and to consider isolated structure and isolated behaviour. Even the poets tell us that we live alone and enisled. Beings, however, only exist in relation, and their relationships take the form, not only of dependence upon the inanimate world, but of a social order. Some animals, such as the ant, cannot exist alone; no solitary ants are known. In other orders, such as bees and wasps, the more primitive members are solitary, the more advanced social. Many birds aggregate in huge flocks during the winter and break up at the breeding season into pairs. Many caterpillars are social, and spin a common web for protection.

SYMBIOSIS.—But not only do we find societies, and even castes, amongst animals; close study of animal structure serves to show that even the individual is frequently an association of two independent organisms living together in some kind of partnership. The classical example of this partnership, or "symbiosis," is that of

lichens. These plants, ever since De Bary's discovery, have been recognized as an association of two entirely independent and dissimilar organisms—algæ and fungi. We now know that many trees and flowers only flourish if they have a certain fungus attached to their roots, and hence the need of removing some of the earth with the roots of certain plants when transplanting them from one site to another. Alders, orchids, and lilies are examples of this kind. Apart from cases of sheer parasitism, the most prevalent association between one form of being and another is probably the occurrence of bacteria. Bacteria are of many kinds: some deadly, some innocuous, some actually helpful. The helpful kinds are chiefly those which have a digestive action upon tough substances taken into the body. Amœbæ are rarely free from such "symbiotic" bacteria, and it is probable that the digestive processes of all herbivorous animals are assisted by these symbiotic bacteria.

SYMBIOTIC ALGÆ —The most remarkable case of symbiosis in animals is one due to the occurrence of a minute unicellular green or yellow alga in the lower invertebrates. It has long been known that many green animals occur, and that their green colour is due either to plant green or to a closely similar substance. There are green as well as colourless Amœbæ, green and colourless

Paramecia, green and colourless Hydra, green and colourless sponges of the same species. Certain of the Acœlomate "worms" or Planarians are green—for example, *Convoluta roscoffensis*, a marine species that is never colourless. Its ally *Convoluta paradoxa* is also green, but the colour is masked by a yellow-brown pigment. Many sea-anemones are green or green overlaid by brown. Many corals are green or brown. In fact, from the Protozoa up to the Mollusca, there are species in each family which contrast with their fellows in occurring either in two colour forms, one of which is green or brown, or in a purely green variety.

For a long time the nature of this colouring matter was disputed, and even now it is not certainly ascertained in a few cases. All those instances we have mentioned have, however, been shown to contain algæ, either of the green or brown order, or more rarely (in sponges and star-fish) of the red order. The peculiar colour variety owes its distinctive colour to the infection of its tissues by a plant.

THE CASE OF CONVOLUTA.—The most clearly ascertained case is that of *Convoluta roscoffensis* (Fig. 15), a small planarian about one-sixth of an inch in length. When walking over the sandy beach of Brittany at low-tide, an irregular green scum may be noticed at about high-tide

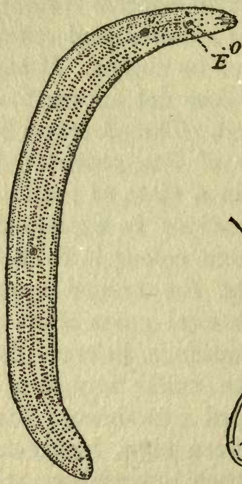
level, apparently pouring out of the sand and extending sea-wards for a few feet in the form of splashes or zones of a deep green tint. On treading near the patches the green scum is seen to disappear into the sand and to rise again to the surface when the disturbance of footsteps has passed away. When the tide rises and begins to lap the patch it sinks rapidly out of sight, and remains below the sand until the next ebb-tide, when it emerges with the water that wells up out of the beach. If the place is marked and the spot revisited next day it will be found occupied as before by a green scum. In fact, year after year these remarkable patches with few exceptions maintain their positions.

Examination of the scum shows that the green colour is due to a vast number of minute green planarian worms which have come to occupy a zone on the beach which is exposed for the longest time to the sun compatible with not being desiccated. Such vast gatherings of green planarians are, at present, known only in Brittany, part of Normandy, and the east coast of Africa; and they are remarkable, not only for their colour, but for the discrepancy between their behaviour and that of their allies. Planarians are soft-bodied voracious animals, living concealed during the day and only emerging at night. Like most .other carnivorous

animals, they are not social, though a few species aggregate under the same stone during their inactive phase. The green Convoluta, however, makes no effort to conceal itself—on the contrary, it lies in as exposed and conspicuous a position as could well be chosen. It associates in vast colonies, and does not appear to live by taking in any solid food. Though it can be made to ingest all manner of fine particles, Convoluta does not do so in a state of nature.

This aberrant behaviour is explained when the nature of the green colour is fully investigated. At first sight the animal appears to be thickly sown with oval green spots several hundreds, or even thousands, in each planarian. These spots are quite unlike any algæ, and it is only after prolonged experiments that they have proved to be green algæ, highly modified in consequence of their association with the animal. In a free state they exist in the neighbouring ocean as minute ciliated "Flagellates." Some flagellates, such as *Euglena* (Fig. 2, p. 19) are a common source of green scum in roads and farmyards, and, like their marine allies, they are constantly tried by the scarcity of nitrogen. In fact, as farmers know, the whole question of crops may be said to be, how, at least cost, to increase the amount of available nitrogen in the soil, and the scarcity of nitrogen

in the sea is greater than on land in consequence of there being no manure, and therefore fewer bacteria to form nitrates. Any means, there-



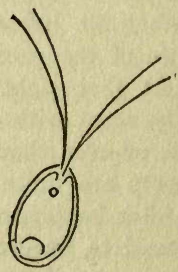


Fig. 15. **Fig. 16.**

Fig. 15.—*Convoluta roscoffensis:* the green social Planarian of Brittany. (× 50.)

This animal contains remarkable green cells (see fig.), to which its colour is due. These cells are represented by the minute dots arranged in rows down the body. Near the front end and in the middle line is the "otolith" (O), an organ for appreciating disturbance. On either side of this is a rudimentary eye-spot (E), by which light and shadow are felt. The other dark spots are local accumulations of used-up green cells.

Fig. 16.—One of the green cells or algæ which infect *Convoluta*. The four flagella or whip-like filaments enable these microscopic organisms to swim actively for a time. Upon entering the body of Convoluta they are lost. (× 1000.)

fore, that will give algæ and diatoms supplies of nitrogen, are readily employed. Now each *Convoluta* lays every fortnight one or more batches of eggs in clutches of six to eight, each clutch being placed in a common envelope and sunk in the sand. The act of egg-laying is accompanied by more or less rupture of the body-wall and the discharge of a certain amount of tissue. On this débris and on the egg-membranes, bacteria assemble and multiply. Here on the site of the patch where thousands of *Convoluta* have laid eggs month after month there is an abundant supply of food material for bacteria, and consequently a great local accumulation of nitrogen. Here, then, colonies of the algæ settle down from the sea-water and multiply, often indeed within the egg-capsules of *Convoluta*.

In a few days (five or six) after the eggs are laid, *Convoluta* hatches as a minute, *colourless* miniature of its parent. Provided with a large ciliated mouth it scours the egg-capsule and its neighbourhood for suitable food. At this stage *Convoluta* will ingest almost any particles small enough to enter its relatively capacious but actually small mouth. We here strike upon the fact referred to on another page, that often only one food is suitable to start the growth of a new-born infant. Just as milk is

the only food for human infants, so *Convoluta*-infants require a special food—in this case the green flagellates, whatever else the young *Convoluta* laps up, without the algæ its growth does not proceed and it soon dies. But, as we have seen, an abundant store of this flagellate exists close at hand, and in the course of a few hours after birth every infant *Convoluta* obtains a supply of the green algæ that it needs. As soon as this supply is obtained *Convoluta* ceases to absorb solid food.

This remarkable result is due to far-reaching changes in the green cells that are ingested. Instead of undergoing rapid digestion they appear to flourish. They divide and re-divide and become spaced out as green dots through the soft integument of the animal. With their entrance and dissemination, *Convoluta* assumes the peculiar habit of its kind, acquiring the social faculty, the sunny position and the stillness that so markedly differentiate it from its allies. The key to these changes lies in the needs of the green cells. Like all plants these require light and carbon dioxide if they are to manufacture and accumulate stores of reserve material. These and other favourable conditions are ensured by the behaviour of *Convoluta*. By their sociable disposition these animals create accumulations of carbon dioxide; in

their soft bodies are bacteria and stores of nitrogen; by their sunlit attitude on warm coasts long spells of isolation are ensured (only one and that a rare enemy attacks *Convoluta*). Little wonder, therefore, that this green flagellate alga finds in the body of *Convoluta* a safe and favourable harbour of refuge. If that were all, however, the case would be one of parasitism and not of symbiosis, for by a symbiosis a mutual benefit is signified. *Convoluta*, however, derives several advantages from the association. First of all, as we have seen, it derives its first food from this alga; but it does this in a subtle way. Occasionally engulfing and digesting the whole green cell, *Convoluta* feeds chiefly by absorbing the reserve-material (possibly sugar) created by the alga together with pigments of the green cell itself. This does not deplete its stores since a wide margin of untouched cells are left over to make good by division the loss of those that are eaten. *Convoluta* has now created an original style of living and is independent of its environment.

Such in brief is the story of *Convoluta*, and it illustrates an extreme case of association, for without its associated green cells *Convoluta* dies. The green cells are probably capable of living independently of *Convoluta*, but flourish best in association with it.

Symbiotic Algæ in the Lower Animals.—The other cases of algæ living on or in various animals represent earlier phases in this dependence. Protozoa, anemones and corals can exist without their so-called commensal algæ but not so well as when infected with them, and like all biological advantages it is not the absolute but the relative that matters; not the capacity to live but the capacity to live better, to grow quickly and strongly, to gain the early supplies of food, the earlier nesting places, and so on. So it is with these coloured animals. They gain advantage over their colourless brethren by the forcing food supplied through the agency of these algal cells. They grow more quickly, divide more rapidly and get rid of their nitrogen waste products more effectually. They possess in these coloured cells a multiplying reserve food upon which they can depend in time of scarcity.

This relation of animals to plants living within them in varying degrees of intimacy, has only recently been appreciated, but is becoming more and more widely recognized. During the last year, for example, the discovery has been made that at least one order of insects, the Hemiptera, possess living in their green or red coloured cells, cultures of yeasts which appear to be transmitted from parent to off-

spring (*e. g.* Aphides); and it is probable that further investigations which are now in progress will reveal the essentially compound or composite nature of many other animals and plants that are now regarded as purely individuals. The idea of symbiosis is rapidly becoming a dominant one.

COMMENSALISM.—The commensal tie, that is, the bond of a common table, is at the bottom of many associations. The feudal system, the servant system, are types of these, and just as the bond which unites groups of men is various—a totem, kinship through father or through mother, payment in kind or in currency—so animal associations are based upon many forms of relationship, partnership or exchange. As we have seen, the lower animals form associations of their own kinds by budding, and associations of a different order by symbiosis.

1. *Inquilines.*—Under this head are included those apparently casual but often important associations which are formed between alien animals. The most important of these is due to the taming and domestication of wild animals by man. This art has had a decisive effect on man's history and to it more than to any other simple factor the origin of civilization is due. Animals have the enormous advantage over other forms of possession of being repro-

ductive. Many of our words, such as "capital" and "pecuniary," remind us of pre-currency ages, when animals were a medium of exchange, a reward for labour and for valour, a means of acquiring retainers and of tilling the ground, and constituted the earliest form of property (Maine, *Early History of Institutions*).

Hermit-Crabs and Anemones.—Amongst animals, associations of unrelated species begun in a casual fashion rarely assume great importance owing to the lack of that characteristically human faculty of improving upon experience. Our common hermit-crabs require the shelter of a gasteropod shell and are never found except in such shells. One species, however, is found bearing not only a shell but a shell crowned by an anemone which does not occur elsewhere. Another is encrusted with a sponge which gradually dissolves away the calcareous shell, and this species usually harbours a Nereid worm which is only found in this situation. How far these are true commensals living at the same table provided by the sea is at present doubtful. The advantages of their mutual association seem to lie in the fact that whilst hermit-crabs are greedily sought after by many fish, the stinging anemone and the spiny sponges are avoided, and therefore the edible hermit is protected by the presence

of its inedible associates. The worm, move-over, is also a *bonne-bouche* for most fish, and therefore gains by lurking in the coils of such shells. More striking instances of such coalitions are seen in the fish *Fierasfer*, which hides itself in the large sea-cucumbers or Holothurians of the warm seas; in the coral reef fish and prawn that dive into the interior of large sea-anemones at the approach of an enemy. Even on our own coasts shoals of fry often accompany the larger medusæ that drift north and westwards in summer, and at the approach of a shadow or disturbance, snuggle under the protecting disc and lie protected by the stinging tentacles. Certain Crustacea, notably the reddish *Hyperia galba*, also associate with the medusa *Aurelia*.

Ants and Their Guests.—Passing from this association of unrelated animals for protective purposes, we may next notice the way in which certain animals employ or permit the existence of others in their family life. In another chapter the care of the young is separately considered and need only be referred to here in order to point out that these brooding and social species often adopt members of wholly unrelated families. Some even go further than this and make expeditions for the purpose of capturing slaves from an allied species. Thus

there are slave-making ants in America and Europe which raid the nests of other species, carry off the larvæ and pupæ and rear them in their own nests. Some ants import the eggs of aphides and rear them in order to possess a store of sugar-secreting "cows." More commonly species of beetles and Hemiptera are introduced by workers for the purpose of providing the inmates with a supply of an ethereal drink which such inquilines secrete at certain points of their bodies. Many of these inquilines are now only found in ants' nests and twelve hundred different kinds of such guests are already known, whilst at least a hundred are known from the nests of the termites or so-called white ants. Some of these guests, such as the beetles, are by no means innocuous, since they feed upon the eggs or larvæ of the ants and divert the workers from their proper duties.

The Cuckoo Habit.—Closely related with this adoption of diverse animals by ants and termites is the cuckoo habit of foisting the care of offspring upon a foster-parent. It is known that the English cuckoo lays her egg down, and after picking it up with her bill inserts it in the nest. The foster-parents in this country include a wide range of birds—hedge sparrows, pipits, warblers, and others, and

in some cases it is asserted that the foster-birds even neglect their own young in attending to the more vigorous demonstrations of the cuckoo nestling. Even after the young cuckoo is fledged and grown, its connection with the nest in which it was reared is probably not broken. The peculiarly variable colouring of cuckoo eggs which often renders them almost indistinguishable from those of their foster-parents is only intelligible on the hypothesis that the hen-bird which has laid in a given nest comes back at the next season to the same nest and if this is occupied she drops her egg in another. This would at least explain why cuckoo's eggs sometimes resemble and sometimes contrast with those of the foster-parents.

Cuckoo-bees.—Amongst bees a similar cuckoo habit is well known. Such cuckoo-bees are, however, even more remarkable than birds, since they have lost the pollen-collecting apparatus of their allies. Cases like these lead on to parasitism in which the young of one species finds food and shelter in or on the bodies of their host. This habit, however, is too large a subject to be dealt with here, and a short account of it is therefore given in Chapter VIII.

Gregarious Habits, Migratory Habits.—The last form of association we can notice is that of flocking: the gregarious habit adopted by

members of the same species. This habit is most developed in those animals which have highly organized and constantly exercised movements, but it is also seen in the young stages of many species which are solitary when adult. Amongst insects, examples of both these forms of herding occur. Many insects migrate at regular or irregular intervals, and at such times assemble like birds in vast flocks. The migratory instinct in some locusts arises in the young before the wings are attained, and vast hordes of a single species may migrate on foot over land and river; others only flock after the wings are fully grown. Some butterflies are migratory, and vast flocks have been described crossing from India to Ceylon. Many species of birds are social at the end of the breeding season on the southward migration, during the summer (puffin, guillemots, terns, gulls), or during the winter (plovers, rooks, starlings). Sometimes the vast flocks of rooks and starlings are composed of non-resident birds driven by severer conditions to a milder climate, at other times they are more probably residents drawn together by abundance of food: for instance, by a plague of wire-worms (larvæ of click-beetles) or of leather-jackets (larvæ of crane-flies). On these, as on so many other points of natural history, there is still much to be learnt. The most impressive features of

these flocks is the dexterity with which they perform complex evolutions, moving in unison and with a wonderful nicety of judgment.

A similar gregarious habit is seen amongst certain fish; usually it is shown either at the breeding season or by the young. Herring shoal on certain grounds for the purpose of depositing their eggs on weeds and stones. Pilchards on the west of France also shoal at certain seasons in the young "sardine" stage. Mackerel appear on our coasts in spring and summer, following the abundance of plankton or minute drifting life. Many other fish congregate during the breeding season on special grounds: for example, in the North Sea and on the Newfoundland banks. Their fry also shoal and exhibit those superbly timed movements which are seen amongst birds. Amongst some animals flocks are formed only by members of one sex. Thus a cloud of male *Bibio* (a two-winged fly in which there is marked difference between male and female) is often seen making rapid flights back and forth over a stretch of water, turning with the greatest ease at each end of its pendulum-like swing. Male gnats are often so numerous as to form a haze that floats over the country-side.

Perhaps the most impressive of all flocking movements is the swarming of hive-bees and ants. In the case of bees there are two distinct

emigrations: the nuptial flight, when the queen is followed by a swarm of drones; and the swarm, when the queen, followed by a host of workers, leaves the hive at its height of prosperity in order to found a new home. In each of these wonderful manœuvres the behaviour of the bees is profoundly different from the normal. The virgin queen, who has previously never crossed the door of the hive, flies far up into the sky and the drones that have spent their lives in lapping honey from the combs suddenly awaken to a true sense of their powers, and, gifted with a prodigious capacity for catching the magnetic queen-perfume by the thousands of sensory pits on their antennæ, pour forth in a great ascending stream until in the distant blue one victoriously mates with the elusive queen and perishes in the act.

In swarming, on the other hand, the workers leave their accustomed routine, a few advance as scouts looking for a suitable tree as resting-place, whilst the remainder to the number of tens of thousands follow the queen in a dazed condition, settling in clouds on the selected spot, and may then be handled with an ease impossible at other times.

Ants on an appointed day, generally a still, hot August day, may be seen issuing in a jet from holes in the ground under which their nests lie.

These living streams are the winged males and females which have never flown before, and which now make their nuptial flight, leaving the workers behind. Their feeble flight is soon over; but for a time the air is thick with drifting flakes. Mating is accomplished in mid-air, and then the living shower descends over the country-side, pours down our chimneys, drifts over the roads and is devoured by all manner of hungry birds and beasts.

CHAPTER VIII

THE CARE OF THE YOUNG

Adolescence.—Animals, like plants, show the most varied devices for ensuring the welfare of the race. In a growing and developing animal the issue of life appears purely personal and self centred. Its internal structure and its inner world are adapted to evoke the unfolding of its capacity for filling a niche in the vast fabric of existence. It goes from strength to strength, from simplicity to complexity, from response to response, and ultimately becomes an organic fabric and constellation moving with definite impulses in a corner of the world: and then, when its life has settled down into a routine of rhythmical action and repose, its behaviour

suddenly changes and its whole reserve of energy and of material is drawn upon for a cause not its own but that of the race to which it belongs. With the advent of this racial impulse its ap-

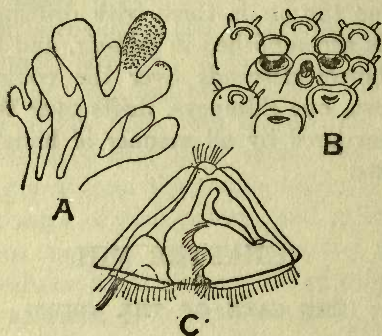


Fig. 17.—A Polyzoon or Sea-mat (*Flustra*).

A. Portion of a colony of *Flustra* such as is often thrown up on the beach. (× 1.)
B. A portion of the same highly magnified to show the polypides or individual chambers of which it is composed. Each polypide has a lid, which in some is closed, in others open.
C. Shows the free-swimming larva of these Polyzoa (× 500). It is a minute, opaque, conical organism, capable of swimming by the aid of the long cilia round its lower border. The body is enclosed in a delicate shell, and ends in a sensitive apex. (After Harmer.)

pearance may attain a more splendid aspect; a new fighting response may arise at each encounter with its fellows. If vocal, its voice deepens; if coloured its coat brightens. It may display its strength and its finery before members of the

opposite sex and there may ensue a selection of the stronger or more attractive mates, who thus obtain a lead over their feebler and less fortunate fellows. But in this momentous epoch no rigid line of conduct can be recognized. Animal behaviour at the mating season offers wide contrasts, not only between members of different orders and genera, but between individuals of the two sexes. The male may attain a size and exhibit an exuberance of colour, he may develop an activity and a series of boldily appendages that contrast strangely with the aspect and behaviour of his desired mate. On the other hand, he may be but a mere forgotten incident in the long life and dominant activity of his widow, for in such cases he dies from natural causes of which his mate must be reckoned as the chief.

Modifications of Sex.—The assumption of sex by animals is, however, complicated by many arresting factors. Neuters, that is, impotent individuals, are known amongst social animals and are familiar to us as "workers" amongst ants, bees and wasps. Occasionally, however, these workers become fertile and then lay a few eggs, showing that they are arrested females. Amongst Termites, the so-called white ants of Africa and southern Europe, there are both workers and soldiers which are, strange as it may seem, arrested males and females. Nor does

the variety of nature stop here, for there are vast numbers of animals, for instance, green fly or Aphides, which for months together and in some cases for years in succession, produce young without the appearance of any males. Lastly, there are some remarkable parasitic Crustacea and certain of the lower worms which attain two periods of maturity under diverse conditions of bodily development. Early in life and at a stage of development that seems to promise a high grade of organization their growth is arrested and they become males. Then degeneration ensues, the plan of organization is lowered and though growing in bulk they become less and less highly organized and in this state become female.

Birth of Larvæ in the Sea.—The eggs of most marine animals are discharged freely into the sea; in such cases the young swim freely or drift far from their birthplace. For example, the sponges, hydroids, corals, sea-mats, all the worms, all the molluscs, most of the barnacles, prawns and crabs and a large number of fish, cast their young upon the waters, leaving them to feed for themselves and to wander whither the currents carry them. The majority of such animals are fixed or slowly-moving creatures, and it is an axiom in zoology that sessile parents have active young. Consequently the structure of the young

stage is adapted to an entirely different life from the one that it will adopt later on. It swims or drifts freely, now nearer the surface, now at a deeper level in order to keep in touch with the oscillations of the minute animal and plant life upon which it feeds. Frequently this food of the young is again different from that of its parents and new means of catching, digesting and absorbing it are required. The result of these adaptations is a creature so different (apart from size) from its parents as to deceive even the elect; and it is only by actually breeding the barnacle, the oyster and the sea-mat, that the connection between their active free-swimming young and the sedentary mother can be realized. Such animals are said to have a *larval stage.* The organs of the larvæ or free-swimming young are not converted directly into those of the adult stage. They are needed for one mode of life and conform thereto, but they are not suitable for the later habits. Hence a more or less violent change is effected and this change is called metamorphosis. Metamorphosis is accompanied by the assumption of the adult habits. The active swimmer touches a rock, floating log, or ship's hulk and after fixing itself becomes transformed into a totally diverse sort of creature with sedentary habits and little intercourse with the moving world around it. Instead of drawing itself

through the water, it now draws water through itself.

Dangers of Larval Life.—The fate of the majority of larvæ is by no means always the consummation we have sketched. The perils of the

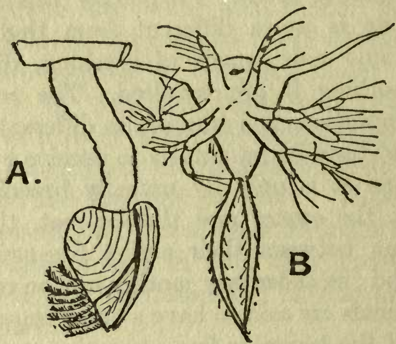


Fig. 18.—A. Goose-barnacle (*Lopas*), such as is found adhering to ships' bottoms by its long stalk. The body is enclosed in a shell, from which the feet project. (× 1.)
B. Free-swimming larva of the same, showing the first three pairs of limbs which are used for swimming and for collecting food. The long processes (near B) help to buoy up the animal. (× 100.)

uncharted ocean are on every side, and even if the more serious dangers of predaceous foes and of starvation be evaded, there is still the difficulty of finding the haven where anchorage may be dropped and adult life assumed. Experience of breeders shows how excessively delicate are most of these larvæ and how meticulous is their

choice of food, choice of water and of other requirements. Probably only one oyster in a million comes to anchor, only one codfish in five millions completes its maturity. The larvæ only live by a hair, and the least change is fatal to myriads of them. Added to these intrinsic dangers as we may call them, are the foes which pursue, harass and devour such tender morsels. Young fish are killed by minute Copepods smaller than themselves, and are engulfed by larger fish, birds and Crustacea.

Size of Families.—In order to compensate for this prodigious infant mortality, animals have to produce vast numbers of eggs, and the drain of such numbers upon the resources of the mother is very great. A turbot may spawn nine millions in a season, a cod five millions, a flounder one million. The result of this vast output of matter and energy is a depletion of the parental stores. The flesh of such fish assumes a watery, flabby texture, the body is thin and pale and the weight much diminished. Such "spent fish" take a considerable time before regaining their prime condition.

Migration to Breeding-grounds.—In rare cases the parents of fish-larvæ and of worm-larvæ make migrations to a breeding-ground. Just as migration in birds is a movement from the feeding-ground to the nesting-ground, so there

are many active marine animals which pass the year, in part in one water to feed, in part in another to breed. Such movements are heralded by a change of aspect in the migrants. Eels assume a shining dress and larger eyes. Many sea-worms or Annelids develop paddling feet instead of crawling ones, their colour changes, their eyes enlarge, and the bristles alter in shape and in size. In this livery, an outward expression of a change of inner state, the migrants embark on their voyage; some, such as eels, hurtling in great companies with the spate down to the sea and far out from the coast to the deep waters; others, such as salmon and smelt, make for the rivers and ascend over fall and weir to the favourite bank.

Breeding Habits of Palolo-worm.—The most remarkable of these breeding migrations is that of the sea-worms. The *Nereis*, for example, that lives in burrows either between tide marks or in company with a hermit-crab (p. 166), forsakes the burrow and striking out with the new oars, directed by the enlarged eyes and guided by the increased sensitiveness, launches upon the ocean. There, sometimes in the heat of the day or in the darkness of night, they row, spurting out their eggs with every stroke and even dislocating their bodies into fragments with the fury of their movements. On the coast of Flor-

ida, Malaya and of Polynesia, the coral rock is full of burrowing Annelids, and amongst these are some species of Palolo, that forsake the rock for the ocean a few days before or after the first full moon in October or November. Their mode of migration is highly characteristic. Each worm before migration consists of two portions highly contrasted in colour and structure. The head-end is coloured just as was the whole body during the previous year and is provided with the normal type of limb; the tail-end, or rather the posterior two-thirds of the body, is now bright green or blue and contrasts markedly with the front portion in colour, in its strong, paddling limbs and in having eyes scattered along its sides. On the appointed evening, all the mature worms turn round in their burrows and lie with their tails, instead of, as usual, with their heads, projecting into the water. Millions of these tails now proceed to revolve and in a few minutes break off and swim away, leaving the severed head-ends in the burrow. As these detached portions separate, their activity increases, and guided by their new eyes, strike away from the shore, spurting out eggs and milt as they go. In a few minutes the sea is converted to the consistency of vermicelli soup, as the dying, contracting, convulsively swimming *disjecta membra* cast their young upon the ocean.

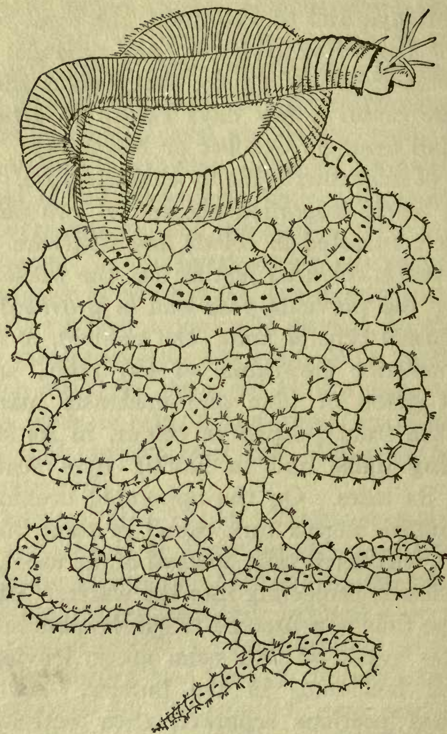


Fig. 19.—The Palolo-worm (Eunice *viridis*) from Samoa. A similar Palolo occurs on the coasts of Florida and of Japan.

This worm consists of a thick, annulated head-end and a long thinner coiled tail-end. The former is reddish, the latter blue, owing to the contained eggs (the specimen is a female). The long tail-end (bearing eye-spots) twists itself off at the last quarter of the moon in November and October and swims out to sea. The head-end remains in the rocky burrow and regenerates a new tail. (After Woodworth.)

Meanwhile the natives of the country having feasted in honour of the occasion proceed to a great haul, and the fate of many thousands of Palolo is arrested at an early stage of development. The severed heads of the Palolo remain ensconced in their burrows. The wound soon heals and growth of a new tail takes place, so that by the time the next October moon comes to the full the same procedure is gone through (Fig. 19).

Even in our own temperate seas there are annelids which repeat this remarkable severance and regeneration of tail-ends. Under the boulders at low-tide there may often be found in spring a yellow-banded *Myrianida*, trailing a slender, whitish tail. On close examination the tail breaks up into a number of joints, but these joints are each an independent and small reproduction of the parent, with the important difference that whilst the parent is sexless, this chain is either a row of males or of females. These form in fact the segmented mature tail-end. They separate, swim away and, after discharging their eggs, become transposed into sexless specimens until the sext spring, when they reproduce the same phenomena; the head-end meantime grows a new tail, which for a year exhibits none of these startling capacities (Fig. 20).

Protection of Eggs.—This habit of dis-

charging eggs broadcast on the water is, however, not the only one. Various marine animals fix a series of clutches to stones, weeds, and even carry

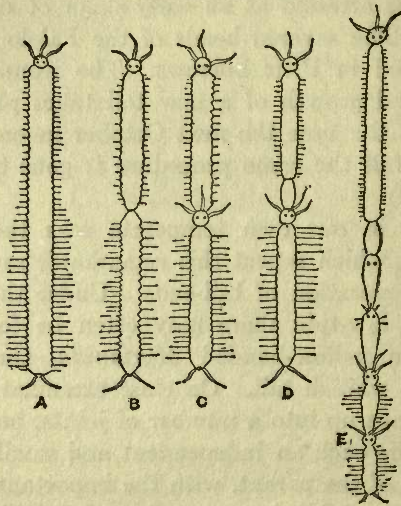


Fig. 20. — This series of figures illustrates the mode of division of a marine worm, *Myrianida*, to form a chain of young sexual forms (E).

The body divides into two portions, the anterior portion remaining sexless, the posterior portion being pushed further and further back by a new zone of growth, which produces the chain of sexual individuals. ($\times$ 1.) (After Malaquin.)

them on their own persons. Such eggs are usually protected by a special envelope: either a band of jelly in which they are spaced out in cross lines and spirals, or a shell. The beautiful

naked-gilled molluscs, *Doris*, *Eolis*, *Aplysia*, cover the coast in spring time with their egg-ribbons; the sea-worms anchor pear-shaped jellies of green or brown eggs in the sand; the dogwhelk fixes its flat conical eggs in rows on the eel-grass; the whelk forms a large cluster of imbricated egg-scales like a cone (Fig. 23). The gobies and sucker-fish have especially careful methods of affixing and of guarding their eggs, and this habit forms the first stage in the formation of nests, in which craft fishes are more adept than is commonly understood.

NEST-BUILDING FISH.—The goby (of which there are many kinds) selects the clean valve of a clam and uses this as the ready-made nest. The pair (for the goby mates with but one and is jealous of any rival) hover round an inverted valve and then the male scoops out the sand from underneath it, forming a cavity, the shell being slightly tilted and pressed into the sand. The female then enters the cavity and deposits her eggs on the lower (inner) surface of the shell. These eggs are somewhat cigar-shaped structures, fixed at one end by a glutinous network that secures them firmly to the shell. Having done her work, the female then exchanges places with the male, who remains on guard, keeping up a constant current of water over the eggs by movements of the pectoral fins, and darting out

at the approach of an intruder. Similar "nests" are made by the sucker-family, by many Planarians and Molluscs, though it is only amongst fish that the habit of guarding the eggs is adopted.

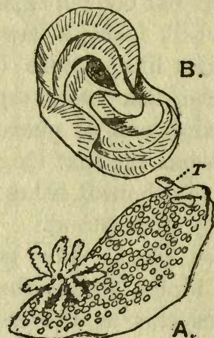


Fig. 21.—A. *Doris*, the sea-lemon (half natural size). This animal belongs to the naked-gilled Mollusca or Nudibranchs, and is commonly found between tide-marks. The head is provided with a pair of sensitive tentacles (T), and the gills form a cluster near the hinder end of the body. The colouring varies greatly, being often of a lemon yellow with purple patches.

B. The spawn of *Doris* ($\times$ 1): consisting of a colourless band of eggs arranged in a spiral and fixed to the under surface of a stone. The number of eggs in such a cluster is immense. The larva which escapes from these eggs is seen on Fig. 28.

Nest of Stickleback.—True nests are made by many different kinds of fish. The common fifteen-spined stickleback associate in pairs, and the male spins a kind of glue with which he binds fragments of sea-weed together into a tubular nest. The female then lays her eggs and these

are guarded by her pugnacious mate. In African rivers many fish are known to construct large

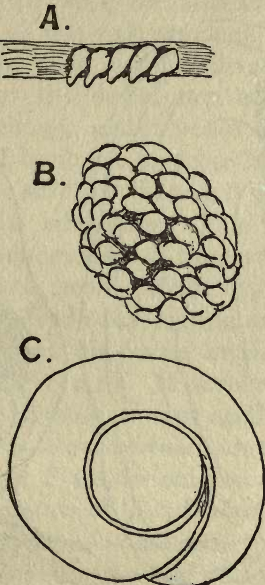


Fig. 22.—Egg-capsules of Gasteropod molluscs.

A. Capsules of *Nassa reticulata*, a carnivorous sea-snail. (× 1.)
B. Mass of egg-capsules of the whelk, *Buccinum*. (× ½.)
C. Spawn of a *Natica*, also a carnivorous sea-snail. This consists of eggs bound in a flat spiral by grains of sand. (× 1.) (From the *Cambridge Natural History*.) The larva issuing from these eggs is seen on Fig. 28.

nests, which may be simply tubular or built of grass-stems or strengthened with layers of stones.

In all these cases of nesting habits, the young when hatched are led in a flock by the male,

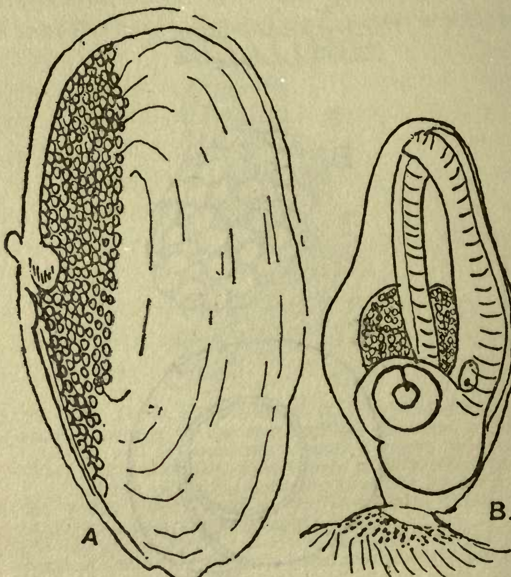


Fig. 23.—Eggs of *Gobius minutus*, the freckled Goby, attached to a shell of *Mya*, the clam. At B is seen one of the eggs highly magnified, showing a young goby almost ready to hatch. The large brain and eyes lie near the fixed end of the shell. A mass of yolk is as yet unabsorbed. The markings on the body are the muscle-segments. (After McIntosh and Masterman.)

very much as a hen leads her chickens. Being cold-blooded, however, fish do not incubate their

eggs, and therein lies one of the chief differences between the nests of birds and those of fish.

Reduction in Size of Family.—We have spoken above of the vast numbers of eggs that are produced by most marine animals in order to compensate for the destruction of the greater part of their young; and it would seem natural, if means could be found to delay hatching until the young were stronger, that such species should gain a certain advantage. This step would involve the disappearance of the larval stage and the retention and feeding of the egg for a longer time. Comparatively few marine animals, however, have adopted this device for shortening the childhood of their race. It involves great reduction in the number of eggs and enlargement of their size, due to an increased amount of food-yolk. No doubt if marine animals were able to raise the temperature of their body above that of the sea, such a method of reducing the size of the family and increasing the size of each member, would be advantageous. Birds, for example, clearly show how rapidly by this means they can ensure the hatching and development of the nestling through the critical stages. But it seems as though the Malthusian system were not adapted for most coldblooded creatures. In spite of this, there are some remarkable cases of its adoption even amongst the marine animals.

Large Size of Shark's Eggs.—All sharks, dog-fish and skates have a small family but are born of a relatively large size. The eggs of these

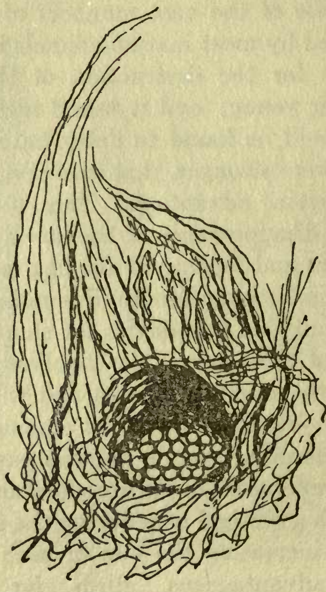


Fig. 24.—Nest of fresh-water stickleback (*Gasterosteus pungitus*) constructed of weeds matted together by the male fish. The eggs are seen within. (From a specimen in the Birmingham Museum.) (× 1.)

predaceous fish are correspondingly big. A dog-fish, two feet long, has eggs that measure an inch in length, or with the egg-capsule, two inches. Such "skate-purses" are well-known objects of

the sea-shore. Those of dog-fish (Fig. 25) are provided with fine tendrils which entwine round weeds and anchor the egg at such a depth as to allow a certain essential rocking of the cradle to be made by the waves. Skate lay their purses on or in sand; and the young, at hatching, are already miniatures of their parent.

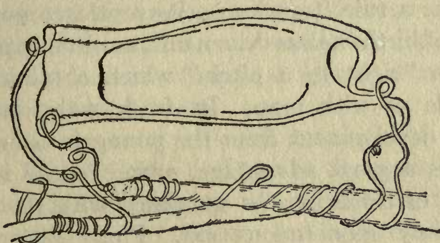


Fig. 25.—The egg-case of the dog-fish moored by its tendrils to seaweed. ($\times \frac{3}{4}$.)

Some sharks that live in deep water in the Mediterranean and off Japan, lay enormous eggs, very few of which have been seen. Perhaps the quaintest egg laid by any animal is that of the *Chimæra*, or of its fellow in Antarctic water, *Callorhynchus*. These capsules are leaf-like and provided with a series of slits through which water can be renewed for the breathing of the contained young.

Families of Fresh-water Animals.—This reduction in the number of the family accompanied by an increase in the size of the infant at

hatching, is a widely accepted principle amongst fresh-water animals and the cause of its adoption is not far to seek. The nestling or young is no longer, when hatched, a larva with habits and structure entirely different from those of its parents. On the contrary, it agrees closely in these respects with its parents, and is therefore able, as a rule, to take up its residence near its place of birth, unless driven out, as often happens, by the "right to a pitch" which obtains with animals as with man. In fresh water such a direct development from the young to a mature state is a great advantage, owing to the inconstancy of conditions as compared with the comparatively monotonous sea. Fresh water has rarely the depth or the extent requisite for maintaining even some degree of constancy. Fresh water runs fast or slow, it evaporates, becomes heated. It freezes comparatively quickly. It is pressed back by tidal waves or spreads out in flood time beyond its normal limits. Consequently for fragile larvæ, fresh water is eminently unsuitable, and only a comparatively small number of animals are known to go through a larval history in fresh water. The pond-mussel, the zebra-mussel (*Dreissena*), the Amphibia, the lamprey, certain insects and the Copepods (or minute, rowing Crustacea such as *Cyclops*) are the chief of these.

Suppression of much Larval Life in Fresh Water.—This fact, the incompatibility of free-swimming larval life with existence in fresh water, explains why so many groups of marine animals have never entered fresh water, and why others have only a meagre representation in it. No echinoderms have ever lived in rivers or lakes. No anemones, corals, or large Medusæ occur in them. The Ascidians and cuttlefish, king crabs, certain groups of worms, and great numbers of fish are always absent.

In nearly every case the explanation lies in their larval history. Animals that cannot produce eggs that develop into young like the parents are unable to obtain a footing in this changeable medium: and even some of those (such as cuttlefish) which produce large young are debarred from the fresh-water life, probably on account of the almost impassable barrier of brackish water that lies between the open sea and the river.

Care of the Young amongst Amphibia.—The eggs of frogs and of certain insects are very easily investigated. Early in the year the frogs wake from their long winter sleep in the pond mud and migrate into the shallows, where they lay their spawn without artifice. This consists of eggs enclosed in an albuminous froth comparable to a number of eggs broken into a basin.

Each egg has a black upper pole and a white nether pole: and is spaced out and prevented from crowding upon its fellows by the "white of egg." The parents take no care of the eggs and make no attempt to form a nest for their reception. Toads, however, fix their eggs in strings to water-weeds, and newts glue them singly to leaves. In exceptional cases newts and frogs attempt to glue the leaves of a shoot together in order to form a rough nest. Among tropical frogs, however, there is an interesting series of nursing habits. The male of *Alytes*, the obstetric frog of Europe, carries the eggs wound about his legs. The South American *Rhinoderma* carries them in his cheek-pouches. The Surinam toad carries the eggs on her back; in some species the eggs are large and the young escape in the perfect state, in others they emerge as tadpoles and go through their development in the water.

AQUATIC INSECT-LARVÆ.—Few insects except beetles are permanently aquatic, but great numbers pass the earlier stage of existence in water. Gnats, mosquitoes, dragon-flies, may-flies, stone-flies and many others lay their eggs in the borders of pools, streams, or even in casual water. The mother, however, gives little care to her young; the eggs are either dropped singly (dragon-flies) or in a group (drone-fly), or in a band or string

of jelly (mosquito). Aquatic insects do not attempt to make a nest (though a few deposit their eggs in the roots of plants) nor do they guard their eggs or young. Though we call some of them aquatic, all insects are essentially aerial creatures, and even the water-beetles fly at night. Fresh water is, from the insect point of view, merely one of their vast nurseries, useful in yielding an abundant supply of nutritious food, but useful only for a time: and, when the supply has served the purpose of providing enough material for the full development of these dominant creatures, the water is forsaken for the next stage, on which the last act of insect life is played out. Hence, perhaps, the perfunctory way in which eggs are dropped by a parent Dragon-fly who the next moment is flying through the air.

Welfare of Land-families.—On land the welfare of the young is most carefully provided for. The difficulties of life here reach their maximum, and not only does the parent in most cases protect her family, but adopts means for their welfare which have no parallel amongst the animals of other media. The number of the family becomes even smaller than in fresh water, the eggs become correspondingly large, or are retained and fed for a prolonged period before birth. All the resources of obtaining heat and of excluding cold are employed, and the parents

do not abandon their young even after they are fledged. The adaptations for these purposes already seen in fresh-water animals are carried to a still further degree.

Dangers of Terrestrial Life.—The reason for these precautions becomes evident when the difficulties and dangers of terrestrial life are considered. The temperature varies, often considerably and quickly, in a way unknown in water, and not only the changeableness but the extremes of heat and of cold are such as never occur in other media. The weight of the body tells at every step, and renders movement a difficult and complicated art as compared with the drifting, almost passive, motion of aquatic life. Food no longer streams by, but has to be sought diligently. Toughness, the note of land life, is characteristic of all its manifestations, and a young land animal may seek far before it lights upon a toothsome morsel. Moreover, life is now lived in the full glare of daylight, in contrast to the subdued tones and deep shadows of the water life, and the difficulty of avoiding watchful enemies is even greater than in the depths.

Eggs and Nests of Land-animals.—The modes of protecting their young against these dangers is well seen if we compare land animals with their nearest aquatic allies. The earthworms lay their eggs in cocoons which are stored

with nourishing albumen and only one egg survives, but the survivor is stronger than the just-hatched water-worm and as advanced as a sea-worm some months old. The house-fly utilizes hot-beds and manure-heaps, where the heat of fermentation enables the young to undergo their transformation in a week, whilst the mosquito, which breeds in water, takes three weeks. The land snail and the slug lay batches of a few large eggs under stones, unlike their allies in the sea and pond, which lay discs or bands of jelly each containing many small eggs. The reptiles choose hot-beds of decaying vegetation or banks of sand exposed to hot sun, and lay their eggs there. Birds heat their eggs with their own breasts and, like mammals, feed their young for some time after birth. Undoubtedly, however, insects show more clearly than any other class the pressure of land life and the most complete adaptation to surmount its difficulties. We may, therefore, refer in some detail to the care of the young amongst insects, more particularly to the order *Hymenoptera*, in which the welfare of the race is most assiduously considered.

Care of the Young among Bees and Wasps. The most familiar of these insects are by no means the most primitive. The hive-bee, the common wasp, and the meadow or wood ant are members of highly organized communities, and to find a

suitable starting-point we have to go to less familiar examples of the order, to the solitary bees and the solitary wasps. These are common and easily found in all parts of the country, yet, owing to their silent flight, inconspicuous size and colouring, are little known and readily mistaken for two-winged flies, whilst Hymenoptera possess four wings.

Burrowing Bees.—If we go along a sunny lane or field track in early summer and notice the footpath that is worn by the side of the road, we shall soon see little patches of freshly thrown earth at the side of small holes, and whilst watching them we may see small hairy bees fly into or out of them, and become aware of a colony that has sunk its shafts in the hard earth and is busy collecting pollen for the young. Careful examination of sunny banks where Composites and gorse or broom abound, soon discovers that these bees are smaller than those of the hive and fly without the hum of a bumble. The smallest of them is only as large as a house-fly and nests in bramble stalks. In the same situations solitary wasps are found, either resting in the inflorescences or busily quartering the herbage for caterpillars.

The habits of these solitary Hymenoptera are entirely different from those of the social kinds. Through the winter they have hidden in the

ground, but on the first warm spring day a few may be seen on the wing. Later on both female

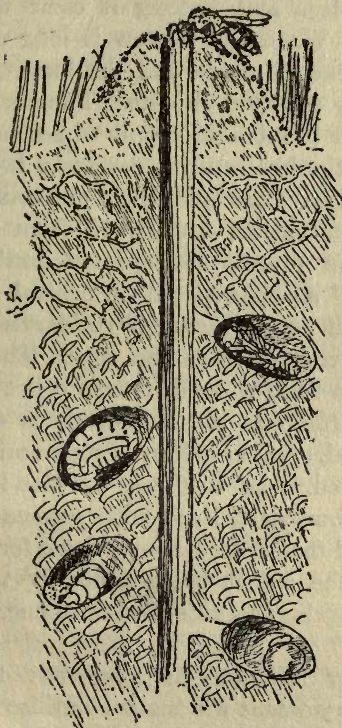


Fig. 26.—Showing the burrow of a solitary bee (*Andrena*) made in pathways and fields. The central shaft serves to carry away water and to act as an exit to the perfect insect. The egg and pollen-food are shown in the lower right-hand figure and stages of development in the others. (From *Riverside Natural History*.)

and male are actively drilling holes with their powerful jaws and scraping the burrows with their fore-legs and kicking it clear with their last pair. When the burrow is long enough, a lateral pocket is made and the locality is fixed in mind by repeated circuits. The bees then fly off in order to secure a supply of pollen. Laden with this the bee returns, descends, lays an egg in the pollen mass and then proceeds to drill another excavation, leading off from the main shaft. The process is repeated until several "pockets," all opening into a central shaft, are stored with nourishment for the larvæ that will presently emerge from the eggs. There is no attempt to form a comb nor to collect or store honey. After one set of pockets is completed and stocked, another gallery is sunk and the process repeated. In the case of the leaf-cutter bees, the burrow is lined with segments of rose leaves, and the carder-bee uses down for the same purpose, the object being probably to protect the grub against its most insidious enemy, damp and "rot."

Solitary Wasps.—In somewhat the same way solitary wasps will make or utilize a crevice, such as a key-hole, and store it with caterpillars or spiders. They sting these animals, numbing them but not killing them outright, and then, often with exhausting labour, haul them to the

burrow. The effect of the sting appears to have a wonderfully preservative effect, so that the wasp-grub which hatches out of an egg laid in the centre of this provender, has an ample supply of fresh food material during its period of growth. The memoirs of Fabre and of Mr. and Mrs. Peckham give a most fascinating picture of these habits of the solitary bees and wasps.

Social Bees.—The change from the solitary to the social Hymenoptera appears to have come about by the young members of the family associating for a time with their parents instead of at once commencing life on their own account. Such a family group has been met with amongst the otherwise solitary bees called *Halictus:* the result of their interaction being the formation of a rough kind of comb. The family, however, do not hold together very long, the children mating and finding homes of their own.

Bumble-bees.—In bumble-bees the stock-mother makes a large cellar or excavation in a bank during the early spring. In this she constructs a few loosely arranged wax-cells, and after placing an egg in each fills them up with pollen and honey. This first batch develops into a brood of small females who remain and assist in the extension of the colony. These are the "workers" though, unlike the hive-bee workers, many of them are capable of mating.

Their numbers increase as batch after batch remain in attendance on the mother-bee, who now rarely stirs out. Finally, towards the end of the season, a batch of male bees ensues, and a few specially large cells are constructed for the growth of the queens. These, without swarming or performing a nuptial flight, mate with the drones and hibernate until the next spring. The workers are worn out with the labours of the nest and appear to succumb before the end of the season.

Mosquito-Bees.—The Meliponas or mosquito-bees of the East seem to give the connecting link between the bumble-bees and the true hive-bees, though little is as yet known about them. They form a definite comb in hollow trees, the worker-cells being hexagonal in plan. There are the three usual castes, queen, drone, and worker, but the drones are not yet idle, luxurious members of society.

Hive-Bee.—Finally the hive-bee exhibits the well-known, highly organized society that is now only met with under cultivation. In this insect, there is no doubt that the queen decides the sex of her offspring, but the conversion of a female egg into a queen or into a worker is determined by the nature of the food supplied to it during its early development by the workers.

Nests and Habits of Ants.—No such evo-

lutionary evidence is as yet forthcoming in the case of the ant, for solitary ants are unknown and have either been supplanted by the more successful societies or occupy an extremely secluded position. The care of ants for their young far exceeds that of any other animal. Their young are not kept in isolated cells, surrounded by food, they are fed directly by the workers, carried about, cleaned, and personally conducted through the whole of their early career. The society consists, not as in the hive-bee of a single queen, winged workers of a single size and drones, but of several queens which are winged only for a few hours during the year, of workers of two or three sizes which never become winged, and of males. The nest is an irregular cavity in the earth with runs uniting its different portions. It may be stocked with fungi, aphides and other living sources of nutriment, but it contains no honey-tubs or pollen. The young are carried to the surface on warm days and to the deeper recesses on cold ones. They are fed by pre-digested nourishment and in many colonies even the soldiers may require to be fed all life long. In order to obtain assistance in this large nursing home, raids are made by many ants on weaker colonies and alien workers are enslaved by their forest-gangs. In these ways we see that the young of social hymenoptera are not left to feed themselves as are the

young of the solitary forms, but are provided with one or more predigested foods by the workers. The nature of these foods determines the status of the individual, soldier, worker, or queen.

Summary.—Looking back over this brief survey of nursing habits we find isolated examples of the retention of the young in many marine animals, accompanied by diminution in the size of the family. Speaking generally, marine animals pour their eggs broadcast, and leave their minute larvæ to complete their metamorphosis unaided and unsheltered, but in every group there are malthusian species which not only restrict their families in number, but enclose them by protective envelopes. The varied experience of larval life in this curtailed and direct development supplants metamorphosis. The eggs become larger and the young stronger at birth.

In fresh water the limitation and protection of the family is more generally the rule. Insects and Amphibia are the only large classes which go through their larval life in fresh water. But the protection is usually of the simplest kind and is confined to the earlier stages of development.

On land the insects form the only class in which the majority still pursues a free larval history. Others develop directly, either growing up into full stature without guidance or

protection, or carried and fed by their parents for some time both before and after hatching. The size of the family (again with the exception of insects) is further reduced *pari passu* with the increased amount of such nutrition.

CHAPTER IX

LIFE-HISTORIES OF ANIMALS

In a previous chapter we have referred to the two chief types of life-histories presented by animals. One is a history of strikingly contrasted events, the other of a gradual development in which phase after phase succeeds one another insensibly. In one of the first phases of life is a minute "larva" swimming freely or a worm-like grub slowly pacing the earth; in the other the young is at birth a miniature of its parent. We must now refer to a few cases in more detail.

Life-History of Protozoa.—Among Protozoa the life-histories are often astonishingly eventful; the complexity being due to the alternation of dividing and of true reproductive phases. An Amœba (Fig. 1), for example, may go for long without more colour in its life than is produced by division into two, but under certain conditions, the nature of which is quite unknown,

its nucleus (that is, the central governing point or structure) becomes multiple and the Amœba passes into a spherical shape enclosing itself in a thick wall or cyst. This is the signal for reproduction. Within this protecting cyst the nuclei break up into fragments and organize minute flagellated bodies around themselves, so that the Amœba is converted into a multitude of active bodies which appear to be all alike. These bodies (gamates) mate in pairs, each pair forming a small Amœba (zygote). These escape from the cyst and grow to their full size. Thus in the very simplest of animals there is division of the life-history into three events: the solitary form, its fission, and the formation of gametes which fuse to form a zygote. These events form two circles: the dividing Amœbæ performing the short circuit, the multiplying Amœbæ the long one. Such a history is typical of all Protozoa, though the details vary in different cases. The chief variation is due to the incomplete separation of the fission products so that colonies may be formed. Such colonies, however, consist of isolated individuals even though they may live in a common jelly or on a common stalk.

Division of Egg-cell.—In higher animals the history also begins as a single cell. This cell is a double structure formed by the union of two gametes. It is, in fact, a zygote. Usually, as we

have seen, it is discharged in vast numbers upon the surrounding water, but it may be retained for a varying period within the shelter of its mother. This cell divides (Fig. 28) like an Amœba, but the halves do not separate, since they are held together by an enclosing membrane and by an intercellular cement. Divisions now follow successively until a ball of cells is formed, the arrangement being determined largely by the size of the initial cell, and this again is due to the amount of food material. As a rule, all the early cells are of the same shape and size, and correspond to a number of Amœbæ held together. Before long, however, the divisions become asymmetrical and the cells become dissimilar. Variation steps in and with it division of labour. The ball of cells becomes a sac with inner and outer linings comparable with the layers of a Hydra. It acquires an opening, frequently it begins to rotate within its capsule, and long before it exhausts its store of nourishment, starts out upon a voyage or journey unless supplied with more food by its mother.

Life-History of Sponges and Hydroids.—Amongst sponges the eggs are usually very small and therefore give rise to free-swimming larvæ. But amongst fresh-water sponges, in accordance with the rule that larval life is discontinued when unwise animals colonize fresh water the eggs are

large, and, after surviving drought or resting through the winter, develop straightway into a small fixed sponge. Amongst hydroids the history is more complicated. The ovum, being minute, develops into a free-swimming egg-shaped larva which drifts helplessly on the sea. If fortunate in finding a holdfast, it anchors and grows up into a branching colony of fixed plant-like aspect. Along the course of these branches, however, certain buds of a peculiar character are formed. Unlike the majority, they are mouthless and enclosed in a protective sheath. These buds correspond to the cyst of Amœba and within them proceed the changes by which the gametes or mating cells are produced or ripened. In some hydroids they remain mere sacs, in others they develop canals and eye spots; and in others, again, they show their proper nature by becoming jelly-fish, pulsatile bells with clapper hanging in the centre (Fig. 29). In a single night, dozens of such medusæ swim away into the sea carrying with them the mating cells and, after growing, discharge the cells broadcast. The cells unite, form a zygote, which again describes the complex circle of existence if spared to do so. In such a history the phases are —zygote—larva.

hydroid buds
hydroid—medusoid buds—medusa-zygote
gametes.

There is thus an alternation of hydroid with medusa-stages or generations. As in the case of fresh-water sponges we have in many fresh-water hydroids a loss of the active phase of life, for in Hydra it is not only the special medusa-buds that are suppressed but the zygote develops straightway into a young Hydra.

$$\text{Zygote—Hydra}\begin{cases}\text{buds}\\ \text{gametes—zygote.}\end{cases}$$

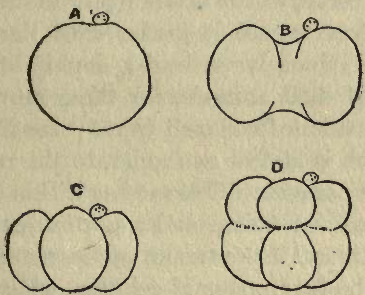


Fig. 27.—Showing the division of an animal egg-cell (*Amphioxus*, a primitive gill-breathing vertebrate). The single cell, or rather zygote (A), is dividing into two at B, and these again into two each at C. Each of these four cells is equipollent, that is, each if shaken apart from the rest is capable of giving rise to an *Amphioxus*, but only one quarter of the normal size. So far we have a simple case of heredity.

The division of these four cells at D into eight is a case of variation. The four upper cells have a different destiny from that of the four lower ones, and none of the eight is capable of giving rise to a whole organism.

Life-History of Echinoderms.—In Echinoderms, Annelids, and Molluscs we see the two

types of life-history, according to the size of the egg and the habitat of the parent. Many starfish, sea-urchins, and brittle-stars develop from the egg into a larva utterly unlike the parent.

In place of the firm radiate body sluggishly moving on the solid ground, the larva has a transparent two-sided body drawn out into tentacles and fringed with cilia by which it glides easily through the water, and drinks as it swims. For weeks to come, its life is amongst the sunlit layers of the ocean where it jostles with the hosts of plankton. Such larvæ lead a double life. They are almost dual animals, for there grows out of their left side a "cœlom" (p. 35; see Fig. 36, p. 250) which is almost as foreign to the rest of the larva as a parasite. This sac has within its sphere of influence a portion, and a portion only of the larva. Around it the tissues are moulded into the form of the future star of echinus, whilst beyond that modifying influence the larva still pursues its own devices. Presently the star within it acquires a mouth, a nervous system, and locomotor organs, whilst the larva on which it hangs has still its own mouth, its own nervous system, and its own ciliated bands. This organized growth, however, soon exhausts the larva that bore it. "My need is greater than thine," is its motto, and the larva is presently depleted of all its material in order to feed the growth that is,

as it were, imposed upon itself. The birth of Eve is no stranger a story than is the development of a starfish or sea-urchin out of the left side of a larva.

Loss of Larval Life.—In contrast to this unequal struggle between the two natures in pelagic, larval echinoderms, the development of protected young proceeds unexcitingly. Such echinoderms live in small families and are nursed on their mother's back. They are often enclosed in a special nursery fenced in by spines. They are opaque, fat with much yolk, and incapable of rapid movement. But even these have to sacrifice some part of their larval organs, which are not so large nor so highly organized.

Larvæ of Worms and Molluscs.—The same story applies to Annelids and Molluscs. The minute young (Fig. 28) are cast upon the ocean in myriads. They develop into top-shape organisms moved by cilia, fed by cilia, guarded by a primitive nervous system, and responding to the varied impulses due to light, gravity, salinity, and other agencies of the open ocean. But in addition to these larval organs and larval activities there are the rudiments of the future Annelid or Mollusc, again in the form of outgrowths from the body of the larva. We have here, therefore, as in the larval history of starfish, a dual organism with two sets of organs, two kinds

of tendencies. One, the larva proper, is simple: its structure is on a level with that which wheel-

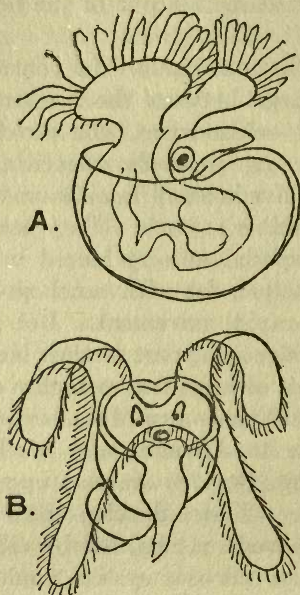


Fig. 28.—A. Free-swimming larva of *Doris*, a marine naked-gilled mollusc. The body is enclosed in a transparent nautiloid shell, from which a pair of swimming lobes project provided with large cilia (highly magnified).
B. Free-swimming larva of a Gasteropod, showing a four-lobed swimming organ, foot and coiled shell. A pair of eyes are present at the base of the two tentacles (highly magnified).

animalcules retain throughout life, that is, an acœlomate double bag with ciliated bands for

locomotion and for nutrition and a simple nervous plate, the whole being unsegmented.

Posterior to this larva, and growing out of it, is a double band of cells—the so-called germ-bands—which has quite other properties. For example, this structure is cœlomic, it grows rapidly in length, it is segmented. The portions of the larval tissues adjacent to it are modified profoundly. A new nervous system forms from them, the segments of which correspond to the divisions of the germ buds, whilst from these cœlomic plates or bands there are formed the muscles, kidneys and reproductive organ of the future worm. The dual organism now looks like a stalked bladder, the larva or head part being swollen and carrying behind it the segmented worm as a sort of appendage. Presently the larval tissues are sacrificed, and out of them a head is fashioned to fit the body. Here again we see an example of that dominance of the cœlom so obvious in the Echinoderm larva and referred to in our first chapter.

Life-History of Earth-worms.—In contrast to this sacrifice of larval tissue in an unequal contest with an alien and higher tissue, there is in the history of fresh-water or earth-worms a smooth course of development. The parent, who is both mother of her own and father of another's family, forms a case by secreting from

her girdle an elastic ring. Drawing herself through this, she slips therein, as it contracts, the egg and a store of yolk. When her head is withdrawn the whole structure closes up and forms a yellow or brown pea-like cocoon in which the eggs undergo their whole development, becoming carved into miniatures of the parent with hardly the loss of a single cell.

Struggle for Existence among Embryos.—But though spared the acute, unequal struggle between the needs of larval and of adult structure, these earth-worms have difficulties of their own as great as those of their marine allies. Being unable to adopt a free life until hatched in the perfect state, it is essential for each egg to possess or acquire enough yolk for the purpose. Three or four, perhaps more, eggs may commence development, and it happens that the yolk available, though enough for one or two, is not sufficient for all. The stronger infants are then under the painful necessity of devouring their brothers, and this apparently they do; so that out of a promising family of six only one survives. The same strange, internecine struggle is seen among molluscs such as whelks, which lay large eggs. Each capsule contains several young, and the strongest hatches with its brothers inside it.

Life-Histories of Insects.—Of all life-his-

tories, perhaps those of insects are the most attractive. At every point they form a complete contrast to those of other animals. The episodes are so shaply defined, the change of habit so marked, and the whole history so comparatively easy to follow that the metamorphoses of insects have received more attention than any others.

These histories are of three kinds. First, there is the most usual episodic type, with a larval preface, a chrysalid text, and an imago conclusion. This kind occurs in most orders. Secondly, there is the history with less moving incident by flood and field. In these cases the young generally resemble the adults, but are without wings. Lastly the life-history may be completed without any marked change of appearance. We may take examples of these histories in the inverse order.

Direct Development.—The simplest insects live amongst moss, under stones on the shore, amongst grass, and even in kitchens. They occur in all latitudes, and very similar kinds live on our coasts and those of the Antarctic. They hatch with the full number of segments, and never possess wings. This direct mode of development is probably the ancestral one, and the complicated histories we are about to describe appear to be adaptations to secure either a more rapid development or a more complex life.

Gradual Metamorphosis.—The next stage is furnished by the Hemiptera (scale insects, aphides,

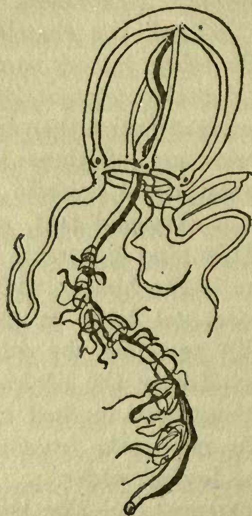


Fig. 29.—*Sarsia*: a medusa budded off from a hydroid. This hydroid is a creature like Hydra, but branched and producing two kinds of buds: hydroid or feeding buds, which remain attached to the parent, and medusoid buds, which feed and breed, break away from the parent-stock and acquire a new type of organization.

The medusa consists of a bell, from the centre of which a long, hollow clapper hangs down, ending in the mouth. This long tongue has the power of budding fresh medusæ as shown.

Sarsia, like nearly all medusæ, is purely marine, transparent and colourless. (× 8.)

etc.) and Orthoptera (locusts, grasshoppers, and cockroaches), in which the young are also born

with the full number of segments, and feed on the same diet as do their parents, but differ from these in not being provided with wings. Generally (see Fig. 30) the wings are only gradually acquired as the animals become mature, the attainment of their full spread and size being a sign of that maturity; but in many plant-lice eggs may be laid by specimens that have no wings and the life-history is complicated by the migration of these destructive insects from one food-plant to another.

Life-History of Aphis.—If we take the common rose aphis as an example, we find during the summer vast numbers of red or green specimens on the terminal shoots of their host-plant. Some of these are winged, some are wingless. On isolating either kind on a shoot placed in water it will be found, in the course of a day or two, accompanied by a little family of young of the same colour as the parent. On again isolating one of these and feeding it with a juicy shoot in a warm situation, it will be found in the course of a fortnight to give rise to another family, and so on. This rapid succession of broods (which may be winged, wingless, or mixed) is composed entirely of one sex: self-sufficient females; and in captivity this history may be indefinitely continued without the formation of eggs or the production of males,

nor is it certain that, even under natural conditions, egg-laying female rose-aphis appear except at extremely rare intervals.

In other species, however—the hop-aphis, for example—the history is more complicated, for the species spends part of the summer on the hop and part on the plum, apparently needing to oscillate between the two food-plants in order to keep up a supply of young. All the specimens produced during the summer are self-sufficing females, and all the broods are born as miniatures of the parent, and not laid as eggs. At the approach of winter, however, and under conditions that are far from being understood, the young develop into two new forms differing very little externally from the preceding generations, with the capacity to grow up into males (winged or wingless) and females (winged or wingless). In some species these mutually necessary and complementary forms occur at regular intervals of so many viviparous generations, but in others they appear at irregular intervals, generally at the onset of cold weather and coincidently with the hardening of the tissues of the host-plant. Such females, unlike those of the summer generations, lay eggs which remain dormant throughout the winter and only hatch at the coming of spring. Each egg then gives rise to a "stock-mother" from which the summer host is derived.

This example of the life-history of plant-lice shows that the complicated cycle is not concerned with the perfecting of a complex organization (as in the higher insects) so much as with the rapid production of colonies during the most favourable time of the year.

Complex Metamorphosis.—In the other insect orders the development almost invariably begins with a hard-shelled egg. The parents being almost without exception aerial creatures usually provided with wings and feeding upon fluid substances, the life-history is divided into two distinct parts: a period of rapid growth under conditions of abundant nourishment and little exertion, and another of complicated development during which the organs for aerial life are perfected and then employed. The period of growth, or larval period, is largely one of mere increase of bulk, but as the life of the "fly" is so utterly different from that of the larva and requires organs, adjustments, and sensations of an entirely different order, it is rarely possible for the larval life to lead straight up to that of the adult. Hence comes the necessity of a transition period when the organs of the larva may be transformed or abolished and those of the perfect insect developed. This transition state is the pupal or chrysalis period. According as the changes during this period are

gradual or violent, so the pupa is active or motionless.

The most familiar case of this complex life-history is that of butterflies, but the incidents are much the same in moths, beetles, dragonflies, two-winged flies and Hymenoptera. The perfect insects are active, winged creatures adap-

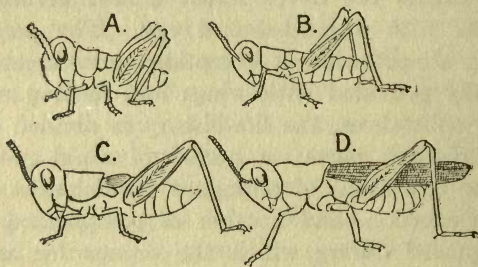


Fig. 30.—Illustrating the gradual development of wings in the grasshopper. (After Packard.)

ted for living either on the nectar of flowers or the juices and flesh of prey. Their larval state is worm-like, immobile, or at least inactive, and sustained by a bacterial of vegetarian diet—a flesh diet. The greatest accumulation of fresh or decaying vegetation is found on land round the borders of sea and fresh water. Hence the eggs of such insects are laid in accordance with the relative abundance of fresh shoots on the leaves of plants or near the margin of

water. There is, however, hardly a situation in which insects are not found. They inhabit the most poisonous drug or the most populous cities, as well as the open ocean and the highest mountains, and their larvæ have an almost equal facility of adapting themselves to conditions of almost every kind. The majority, as we have said, feed on waste nitrogenous substances, or on the verdure of the earth, but there are many which attack timber, cloth, books, and dried substances of any kind.

LIFE-HISTORY OF DIPTERA.—Perhaps the most remarkable instances of larval adaptation to varied surroundings are found amongst the Diptera, or two-winged flies (including the various forms of flies found in houses, the blood-sucking flies, the daddy-long-legs or Tipulids, the midges and tsetse-fly). The common harlequin fly, or midge, *Chironomus* for example of which there are two hundred British species, lays its eggs in casual water, on the sea-shore, in running streams (Fig. 31); whilst closely-allied biting midges (*Ceratopogon*) breed under bark and in wet hollows amongst timber (Fig. 33). The buffalo-fly (*Simulium*), which is such a plague to man and beast in most parts of the world, though harmless in Britain, lays its eggs in rapid streams; whilst the gaily-coloured hover-flies, according to their kind, seek out rose-bushes

covered with green-fly, a putrescent pool, or the nest of some bee or wasp.

The larvæ that hatch from eggs placed in such various situations offer a bewildering variety

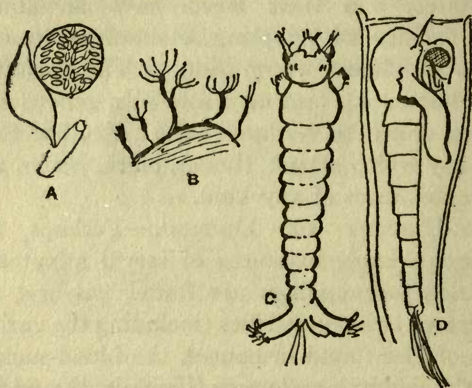


Fig. 31. —Life-history of *Chironomus pusio*, a gnat of mountain and moor.
A. The egg-mass fastened to a leaf in a Devonshire stream.
B. The cases made by the larvæ and pupæ whereby they anchor themselves and catch prey (a pupal case is seen on the extreme left).
C. A larva magnified, showing the antennæ, jaws and thoracic feet. At the end of the body are two abdominal hooked feet.
D. The pupa in its case. (After Mundy.)

of external form. Some (such as those of gnats) are active, red, green or colourless worm-like creatures, sometimes inhabiting tubes, sometimes pursuing a roving life. The tubicolous species possess divers sorts of casting nets or collecting

hairs by which they intercept the drift-life of the streams and inhale it, others (such as the rat-tailed larva of the drone-fly) simply engulf the decaying matter of some standing pool. The leather-jacket or larva of crane-fly eats the roots of herbage; the frit-fly larva devours turnips; that of the Hessian fly injures the stems of corn. So great is this adaptive modification of structure to habit that quite similar flies may have very different larvæ. The general principle of structure, however, is much the same in all. The head of the larva is usually small; the body is uniformly segmented, and not divided into thorax and abdomen as is that of the fly; and the organization is such as to enable rapid growth to take place without depletion of the stores of energy and material needed for active sustained movement or for the development of complex sensory organs.

The length of larval life amongst the Diptera varies greatly, partly according to the nutritious character of the food, partly according to the temperature of the surroundings. A house-fly may, under warm conditions, complete its larval development in four days; under less favourable surroundings it may last from two to three weeks. In the same way the larval life of other Diptera varies according to the temperature and the stimulating or impoverished nature of their

food. In a few remarkable flies, of which the dreaded tsetse-fly (*Glossina*) is one, the larval stage is passed in the body of the mother, and the fly is born as a full-grown larva which immediately changes into the pupal state.

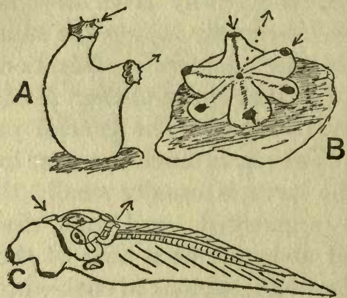


Fig. 32.—Ascidians, or sea-squirts.

A. A simple solitary form, showing the ingoing and outgoing currents of water that provide it with food and oxygen. ($\times \frac{1}{3}$.)

B. A colonial form (*Botryllus*), consisting of six individuals, each with a separate inhalent opening but only sharing in a common exhalent pore. ($\times$ 6.)

C. Shows the free-swimming larva of this group. The larva is tadpole-shaped, and the tail is provided with an upper and under fin. The study of this larva has led to the discovery of the true position of Ascidians in the animal kingdom. ($\times$ 60.)

THE CHRYSALIS-STAGE.—This pupal or chrysalid state is requisite, as we have said, owing to the reconstruction of the larval tissues to form those of the fly. In some gnats the pupa is never quite inactive, but in most flies the changes that go on within it are so great as to

render a motionless period absolutely necessary. During that period the muscles, skin, alimentary canal, and other organs (except the nervous system and the vascular system) are eaten up; then from the pulp there is produced the material for wings, legs, antennæ, air-sacs, and other organs. The nervous mechanism is perfected, and when hatched and dry the fly makes its first circuit as accurately as if it had practised the movement for days.

DEVELOPMENT OF VERTEBRATES.—The life-histories of higher animals can only be very lightly dealt with in such a sketch as this. The fixed sea-squirts illustrate the larval type of history. These strange drinkers and sifters of the sea cover the rocks and stones of our coasts, and were for long placed with the Invertebrates on account of their unsegmented bodies, unmarked by any complexity of structure except the filtering throat. Their development completely altered such conception of their place in nature, for it was found that they hatch as Tadpole-like organisms provided with a tubular nervous system underlain successively by the forerunner of the vertebral column and by the pharynx. This combination of characters is only found in one large phylum of animals, namely, the vertebrates, and accordingly to that phylum sea-squirts belong.

The free life of these larvæ is limited to a few hours or days, after which they settle down by the head, fix their forehead on a rock by tentacles and proceed to twist the body through an angle of 90°. Meanwhile the same curious double change takes place in them as in insect pupæ. Some of the organs disintegrate and form a pulp, whilst others differentiate and develop at their expense. The hollow nervous system is concentrated into a minute knot, the eye drops out, the nose disappears, the muscles fall to pieces. On the other hand, the throat expands and its perforations become multiplied, supported by bars and supplied with a rich network of blood-vessels. The larval sensations are lost and ultimately the psychical grade of adult life is the very lowest of which we have any record.

Larval Traces in Vertebrates.—In higher vertebrates the traces of such larval life are hard to find. There is no such wholesale dissolution and reconstruction in them as in insects and sea-squirts, but still even in man there are certain organs which subserve only a temporary purpose in early life and disappear to form food for others at the time of birth. For example, there is running through all vertebrate animals a perforated throat or "pharynx" (Fig. 8, G), functional in fishes as the gill-cham-

ber, used also in the early life of frogs for the same purpose, but persisting in a form useless for the purpose in reptiles, birds and mammals. The primary meaning of these slits was to allow the passage of aerating water over the gills. They were breathing organs and are such in fish and some amphibia, but they were more than this. The walls of these gill-slits gave rise, even in gill-breathing vertebrates, to structures which, uniting together on each side of the neck, form a gland, in shape resembling the inflorescence of the thyme and hence known as the "thymus." This is the structure which disappears in man about the time of birth. It is one of those larval organs which we have mentioned, elaborated from the bars of branchial basket-work, which seems to undergo just such dissolution as the muscles, glands and other larval organs of an insect pupa. In spite, therefore, of the enormous gap between the lower vertebrates or invertebrates and man there are still indications even in him of that larval history which they more fully play out in their development.

THE RECAPITULATION THEORY.—In conclusion a word should be said on the question of the value of life-history as a pedigree document. Do animals, in Marshall's phrase, climb up their genealogical trees; or are they re-

capitulating their ancestral history only in such a general way as to render any deduction in a particular case untrustworthy? The question is one of enormous difficulty and the con-

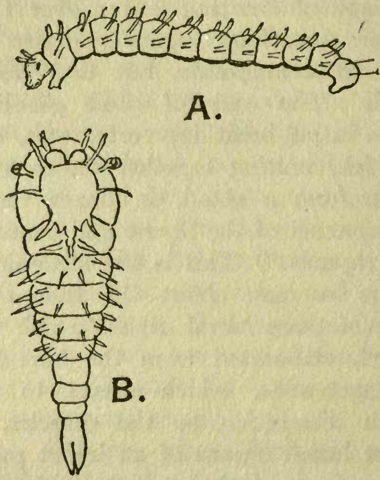


Fig. 33.—Larva and pupa of the minute biting midge, *Ceratopogon*. This tiny insect is very common in gardens, and bites at sunset. Its larvæ (A) live on the bark of oaks and of other trees, and are 5 mm. in length when full grown. Its pupæ (B) live in the same situations. (After Johannsen.) (× 15.)

fident affirmative of twenty years ago is now rarely heard. In the first place, the study of the development of organs leads to the conclusion that there is a broad recapitulation of past history in the development of the individ-

ual. The heart, for instance, the ear and the eye, even in man, do go through stages of development which are retained by lower vertebrates, but there is strong evidence that the man or animal as a whole is by no means following the succession of form which characterized his or their predecessors. Man is at no time a fish, an amphibian or a reptile, as it is somewhat crudely put. A chick-embryo, at four days old, represents an organism incapable of independent life ; a pupa also is incapable of free life. Hence arises the baffling result that, as has been said, the older history like a papyrus has received additions and alterations of a later date, and we know not how much of the altered development to attribute to that added matter. Moreover, one of the most primitive animals in the world, one of the most important links in the chain of evolutionary evidence, is the caterpillar-like *Peripatus*, a link between Annelids and Arthropods, but the development of *Peripatus* is direct and sheds no light whatever on the Annelids or Arthropods that it links up. So it is for the oldest animals in nearly all cases: scorpions, lamp-shells, tusk-shells, *Nautilus*, *Ceratodus*, primitive insects ; these are the aristocrats with long pedigrees, living fossils, and none of them has a life-history that throws any im-

portant light on their past. Whatever conclusion we can draw from animal histories, one, at any rate, is sound, namely, that (in critical cases such as we have mentioned) the earlier chapters are entirely missing. The study of heredity under Mendel's stimulus shows how ancestral qualities may be bred out, and the whole trend of opinion is at present to place the crucial evidence for past history not in development and not in breeding but in the records of the rocks.

CHAPTER X

HEREDITY AND VARIATION

By heredity is meant the degree of likeness between parents and their offspring. Originally the term implied succession in tenure, but as in the case of so many scientific words, the original significance has been altered and the alteration established by custom. In its modern sense heredity is a measure of the resemblance between two or more generations of the same family.

In ordinary speech heredity is spoken of in many illegitimate ways. Sometimes it is regarded as a force by which the recognizably close resemblance of two or more successive

generations is to be explained. Frequently it is thought of as a principle which in some unexplained fashion endows father and son with their common likeness. There is no justification, however, for regarding heredity as in itself more than the expression of complex interactions. The causes of the undeniable likeness are undoubtedly complex and far from being fully understood, but the expression they give rise to in each generation of a family may be simply so many feet high, such a colour of eye or hair, such a shape of hand or of ear. Heredity is really, then, a measure of the effect or likeness.

Relation of Heredity to Variation.—When, however, the causes of these likenesses are investigated we still speak of the study of heredity. In this deeper aspect of the problem it is not the symphonic expression, the outcome of the causes, which is insisted upon so much as the notes and phrases, the analysis of the composition. We are no longer measuring the likeness between sons and fathers, but are attempting to understand why a father with the note of height and a mother without it, have children of a composition that differs from that of either parent. The subject passes into the analytic phase, and it is only on realizing the complexity of the composition that

we recognize its symphonic nature. If we compare the leaves of a tree with those of a sapling sprung from the tree we may be able to express the result quite simply. The degree of likeness is heredity. But we are not satisfied with that result; we wish to know what causes induce the degree of likeness. We find the leaves of the parent tree are not all alike, nor are those of the daughter tree; and we have first to determine how far we can express this diversity between the leaves of each tree. This diversity we call variation. Variation is thus a measure of the resemblance or difference between members of an individual or between members of a family. But heredity implies genesis. It involves two successive generations however produced, and it is this genetic factor which distinguishes heredity from variation.

Variation is no special attribute of life. We can speak of the degree of resemblance between varieties of soils, of hard or soft water, and of many other objects, though in a biological sense variation is still conveniently employed as a measure of resemblance between comparable individuals or parts of individuals, whether of the same generation or not. We can speak of the variation of cloths, calicoes, cotton, and also of the human skull, but the value of the observation depends on the com-

parable nature of the material, and when we have such data arranged in successive generations then the variations become heredity and only then. The notion of genesis of succeeding families is essential to heredity. It is not essential to variation. There is a lapse of time involved in heredity, whereas variation is best expressed as a measure of likeness between contemporaries. The likeness between brothers and sisters is measured by variation; that between both of these and their parents is an expression of heredity; and we can measure the likeness of all children of the same age, or of the same nation. Some basis of comparison there must be, and those results are of most value in which the material measured is most closely comparable; *e. g.* the parts of an individual or the individuals of a family. Before the study of heredity can be fitly undertaken, therefore, it is necessary that the problem of variation should be understood, and this precaution is now widely recognized since the question of variation underlies the modern theories of evolution.

Animal Classification.—Before the problem of variation in its biological sense can be appreciated, it is necessary to state the principles of classification. Animals are not only organized structurally, they are also organized

in groups subordinate to more comprehensive groups: they are segregated into battalions and companies. Man, for example, is a large division, composed of many races, and usually regarded as forming a single species made up of these geographical races. Herrings, partridges, cockles and many other widely spread animals are likewise composed, not only of so many male and female individuals, but of these grouped in races so that an expert can place an individual roughly in the variety to which it belongs, and can often say from what part of the country it has come. Any widely distributed animal is found to fall into a certain number of these geographical varieties, and it is only by lumping these races together that we get the idea of a species. Such lumping may even go beyond its legitimate bounds. All dogs, for example, and all horses are supposed to form a single species in each case, but such an expression leaves out of sight the fact that we are attempting to impose upon a cross-bred animal the terminology of a pure-bred one. Dogs are probably descended from more than one wild species. Horses show many indications of an equally mixed descent. It is better, therefore, to begin by recognizing the the racial characters before attempting a synthesis such as is implied in the word species.

The study of variation, therefore, has to reckon with the tendency of a widely distributed animal, not only to show individual differences between members of contemporary and of earlier generations, but also to vary in a definite manner over a certain district or under certain conditions. In a word, variation deals with individuals and with geographical races. For example, we can measure the height of the men in an army, but the results will be of little value if the army is of mixed origin. To compare individuals effectively we ought to know that they have a certain relationship to one another, and the closer the relationship the more valuable are the results. All the men of a race would in a certain sense offer comparable material, all the men of a nation would constitute a still better foundation for useful results, but to use them to the best advantage it would be necessary to have data as to age, up-bringing, and so on.

Variation in Nature.—Having realized the necessity for precaution in obtaining comparable data for the study of variation, a few words may be said about the kinds of variation which occur in nature. Every one realizes individual differences in man, and those who are engaged in agriculture realize an individuality in cattle, sheep and dogs, even when,

to the inexperienced observer, the members of a flock, herd or pack may look almost exactly alike. Increased familiarity with animal life shows that this phenomenon is not limited to man and domesticated animals. The members of wild animals' families show individual differences though we are less acquainted with them. A sweep of a shrimp-net over the seaweeds on a rocky coast will disclose a number of specimens of *Hippolyte varians*, hardly two of which are alike; some are green, some red, some brown, some are spotted with blue, other are not, some are uniformly tinted, other are marbled or lined with colours. We do not know, however, whether these casually collected specimens belong to two or more families. But even if we take the offspring of a single individual, say a green specimen, we find that some members of the brood are different in colour from the rest, some are harder, some have the rostrum (that is, the pointed spine or nose in front of the head) with so many notches, others have fewer, and so on. Still better is the case of the eggs of the common house-sparrow. With most British birds the eggs of a single clutch are apparently exactly alike in shape, size, weight and colouring. In the sparrow, however, the eggs differ among themselves to an extraordinary degree: still more do they differ when several

clutches are compared. In just such a way is there individual variation of greater and of lesser extent amongst animals generally.

Departure from Symmetry.—But the nature of variation is more deep-seated than individual or racial differences. Regarding the individual as an organization, as a collection and synthesis of members, we have departures from symmetry brought about by one or more members developing more strongly than their fellows. For example, all animals that creep, walk or fly are bilaterally symmetrical, they have right and left sides, and we unconsciously assume that the sides ought to be alike or rather complementary. A tailor, however, knows that our shoulders are not symmetrical, and that usually the right side is either more strongly developed or more rounded than the left. Our eyes look alike, but the eyebrows are often markedly different in behaviour, and an optician readily discovers the inequality in strength of the left or right eye in many people. The hands are always different in their capacity for drawing, writing, exertion, indicating that the brain is not truly symmetrical. In fact, all the evidence goes to show that the two sides of our body vary independently.

Influence of External Conditions.—But not only are there individual variations which ex-

press inborn differences between members of the same family or of the same body. In addition the influence of altered conditions, both external and internal, modify an individual and produce an effect in which the shares due respectively to nature and to nurture are hard to estimate. Take, for instance, the influence of meat. Long ago John Hunter, the famous anatomist, fed gulls for a year with a diet of grain in place of their usual food of fish and soft food. The stomach of these birds developed a more muscular coat and its lining assumed the structure of a gizzard. More remarkable still is the annual change of structure that occurs in the same gull according to Dr. Edmonstone. In certain districts these birds feed part of the year on fish and during the rest on grain. During the period of the fish diet, the stomach assumes a soft structure characteristic of the bird in most districts throughout the year, but when the gulls take to the fields the lining of the stomach acquires a gizzard-like appearance, which is again replaced by the less muscular coat and softer lining when the gulls have exchanged the fields for coastal life.

Influence of Light on Flat-Fish.—Again, the lower white side of flat-fish (Flounder) can in the course of a year be made more or less pigmented by exposing it to light reflected from

below instead of from above: and it is not an uncommon thing to find "ambicolorate" flounders or plaice in nature; that is to say, specimens which are coloured on both sides. In this case, however, we do not know that the habits of these fish are such as to expose their under surface to an especial amount of light.

A more indisputable natural experiment is the one which has resulted in the remarkable coloration of *Echeneis*, a fish often attached by its head to ships or sharks. The dorsal fin of this fish is modified to form a sucker by the aid of which it often lies inverted, its upper surface being turned downwards, its lower surface upwards. The resulting coloration is exactly the converse of what usually obtains, for such fish are light above and dark below. We have, then, variations brought about by change of conditions and all recent experimental work goes to show that plants and animals are susceptible of far-reaching changes in appearance and structure, and even in modes of reproduction, when submitted for one or more generations to the influence of an environment different from that in which they normally develop. Here, again, we are struck by the reserves of capacity in animal life. Individual life appears to be only a partial expression of its total capacity for assuming form or structure and of initiating developmental changes in offspring.

Variation due to Internal Causes.—Variation, however, not only arises in connection with external changes. It may also be induced by internal ones. We are coming to realize that every animal is not only a constellation of cells arranged in tissues, but that the crevices of this system are filled with a fluid medium, blood or lymph, possessing a surprising richness of capacity. Bathing as it does every element (or "cell") in this constellation, this "milieu interne" is a sort of inland sea washing the shores of susceptible and ever-changing islets which are absorbing nourishment from its waters and discharging waste into them. This inland sea is the complement of the environment. Its waters flow and ebb, bearing food and oxygen, like the outer sea; and just as when we modify the quality of sea-water, animal life feels the change for good or for ill, so when the internal sea is altered the body responds as by fever or lethargy, by increased or by retrograde development. These two seas, in fact, act upon each other; the environment produces its effect upon animals largely through acting in the first instance upon this inner sea, which in turn affects the islands of cells and the archipelagoes of nerve and muscle. Change of environment, then, works chiefly indirectly upon the body through the medium of the inner environment.

Factors governing the Internal Medium.

—But this internal medium has its own regulations and governance. It is specific for each kind of animal or at least for the majority. The phrase, blood-relationship expresses more than was realized in the minds of those who coined it. By the blood alone the relationship of an animal can be determined even down to the particular species to which it belongs. Such facts show that there must exist a mechanism for creating and maintaining this constancy. The medium itself is of a great complexity, recalling again the sea of which it is the analogue. Some of the substances in it are even the same as those which occur in the sea, such, for instance, as common salt. Indeed, amongst lower aquatic animals there may be an exchange of substance directly between the outer and the inner medium, but in the higher animals the blood is only indirectly related and to a slight extent with the food, air or water of the outer medium. Its composition is governed largely by special "glands" which extract substances from the incoming blood, work them into new combinations and with due reserve discharge them into the outgoing bloodstream, from whence they find their way into the lymph and so to the very crevices of the organism.

Such glands, for example, as the thyroid, thymus, suprarenals, are employed in the work of regulating the composition of this shallow sea,

and it seems probable that many organs, if not, indeed, all the tissues, contribute to the final result. But there are some which contribute more largely than others, and change in these brings about a marked alteration in the feeding power and other properties of the medium upon which the whole body depends for the continuance of its healthy, normal existence and growth. For example the thyroid exerts a far-reaching influence of this kind and though it varies considerably in man without producing any ill effects, such variation has a limit; and if the thyroid effluent is either insufficient in quantity or defective in quality, the whole body suffers from starvation just as real as if food of the ordinary kind were withheld. In a child with imperfect thyroid the body becomes stunted and growth ceases, the mental faculties may be arrested and feeble-mindedness ensue; and the trouble may hang out a signal of distress by the assumption of goître or may lie concealed.

Variation, then, is caused by internal as well as by external changes. So strongly indeed do we become impressed by the facilities for alteration in the external world and in the internal medium that we begin to wonder how the constancy that we all admit, the average size, shape, structure and behaviour of each species of animal, is maintained. We begin to perceive the neces-

sity for a regulative machinery which must so influence or counteract these tendencies to vary as to allow of only a comparatively slight degree of divergence from the standard of each animal kind. Such governance, however, is at present far beyond our ken.

The Problems of Heredity.—Having now realized to some extent that the orderliness of nature, the sharp lines that demarcate the animal world into battalions and companies, genera and species, is a balance struck between tendencies to vary (centrifugal tendencies) and tendencies to typify (centripetal tendencies), we come back to the problems of heredity which as we have defined them are the relations between successive generations. The nature of these problems will become clearer if we take an example of the kind of material with which heredity deals. The enormously complex nature of human inheritance renders a simpler example necessary.

Division of Cells.—Amongst protozoa the process of fission or division leads to the multiplication of isolated cells whereas in higher animals the cells cohere and form tissues. Each time that a *Paramecium* divides, the body of the parent is shared by the daughter-cells, and the likeness of daughters to one another and to their parents is largely due to the mere slicing of the latter in two, accompanied, however, by other

changes which are also only a dividing of substance into equal halves. Such dividing cells are like the cells of the animal body, they are somatic cells; and just as our hair grows by multiplication of cells at the hair-follicles so the *Paramecium* grows even though its cells fall apart from one another. Fission is simply a form of growth.

Heredity is the Study of Symmetrical Divisions.— There is, however, one important difference between the division of a *Paramecium* and that of a tissue-cell. In *Paramecium* the two daughter-cells have each to complete a portion of their bodies by growth. One has to make a new "tail," the other a new "head," whereas when two tissue-cells are formed by division of one, each of the daughter-cells has no such "ends" to form. *Paramecium* produces a succession of new individuals which are not optical images. The like parts are alternate in *Paramecium* and adjacent is a tissue-cell. The symmetry is also different in the two cases: the daughter-cells of *Paramecium* are related to one another like the right and left hands, daughter-cells of a tissue-element are mirror-images of each other. Viewed from this aspect, heredity is a study of such symmetrical divisions. (Fig. 34. See Bateson's work, p. 256.)

Variation, the Study of Asymmetrical Divisions.—Now suppose that the plane of division does not pass exactly transversely to the

body of the parent *Paramecium*, but, as sometimes happens, cuts it irregularly so as to leave one daughter-cell with a process and the other with an indentation. The symmetry of the two

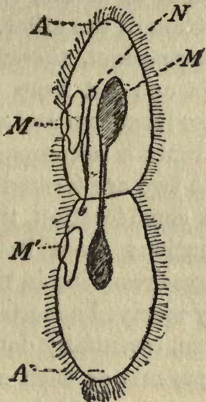


Fig. 34. — To illustrate the relation of heredity to symmetry. A dividing *Paramecium*, showing the two mouths (M, M′); the anterior end and the posterior end of the two daughter-cells. The two nuclei are also in the act of dividing. The symmetry of the two daughter-Paramecia is really not complete. The anterior has to regenerate a tail-end, the posterior has to re-form its head-end.

is now no longer what it was, and two variations have been produced. Variation then is asymmetrical division, and from such a standpoint the separation of tissues in a dividing egg begins with the first asymmetrical division. (Fig. 35.)

Nature of Gametes.—The case of *Parame-*

cium is, however, simplified by the fact that the body of the parent is merged in that of the children. When conjugation occurs (p. 21) there is an interchange of the two cells, so that when they separate and begin to divide, each carries away with it some portion of the other. The daughter-cells of any *Paramecium,* therefore, are derived not merely from one but from two parent cells and each of these from two and so on. The mingling of two parents is accompanied by complex changes, and the two are termed gametes. It results from this consideration that the children contain contributions from both parents (the preliminary process resulting in the casting out of much previously received ancestral contribution), and are, therefore, essentially double structures if we regard the parents as each a single one. In most cases the gametes do not separate after conjugation, but remain fused together. Such a fused mass is termed a zygote and will presently divide into cells and form a fresh individual.

Double Nature of Zygote.—In higher animals the same process usually occurs. The egg or zygote is a double structure derived from both parents. It divides, but the products are at first mirror images of one another and remain united. Presently there comes a division which cuts the egg into right and left halves, the foundation of the future sides, and forms the basis of a new type

of symmetry. Lastly the cell-mass becomes differentiated. That is variation and is essentially due to asymmetrical division. The study of heredity is the study of these variations, but we cannot often trace the obvious characters which distinguish grown individuals such as hairiness, height, colour, and so on, to that point in development at which the asymmetry first began. If we could, an enormous advance would be possible in the study of heredity.

MENDELISM.—In place of such intensive study, heredity at present deals with immensely complex symphonic expressions: and has made such advances that by its aid a correct result can be foreseen even when the particular "cross" has not been made before. This result has been rendered possible by the discovery, remarkable alike for its profound nature and the neglect it met with, that on crossing contrasted sweet peas, the offspring display in their characters a simple multiple relation, the parental characters appearing in the first or (on self-fertilization) in the second cross not mixed or averaged but segregated out in a definite proportion. Thus a tall pea (T) crossed with the pollen of a short pea (t) gives all tall in the first generation, and when these are self-fertilized their offspring are tall and short in the proportion of three tall peas to one short. On repeating the process, the tall peas are seen to be-

have in one of two ways. Some (TT) yield tall plants only, others (Tt) tall and short, again in the proportion of three tall to one short, whilst the short or bush peas (tt) yield short only. In this way the pure lines are extracted from the impure, or, to use correct language, the homozygotes are separated from the heterozygotes.

Factors in Heredity.—In such a way the factors for tallness and for shortness are seen to be definite transmissible qualities even if we know nothing about their mode of action. These factors are pure in certain offspring (homozygotes) mingled in others (heterozygotes); but when mingled they can be separated out by breeding, though never perfectly—a certain number of the mingled strain always reappears. The important points to notice are the purity of the "extracted" strains and the simple proportion they bear to the mingled strain. Thus, if there be 2 n heterozygotes there will be n tall and n short plants of the pure strains.

This result, the extracting or segregating out of plants with a certain property (such as the property of growth to 6 feet or of growth to only 2 feet) from a mixed race is the central feature of the great discovery made by Gregor Mendel, in the monastery at Brünn, in Bohemia, and published in 1866. If we use the term allelomorphs for those alternative characters (such as

tallness and shortness of habit, yellowness and greenness of seed) then we can say that when the allelomorphs segregate out, the homozygous offspring breed true to the character in question, irrespective of their ancestry.

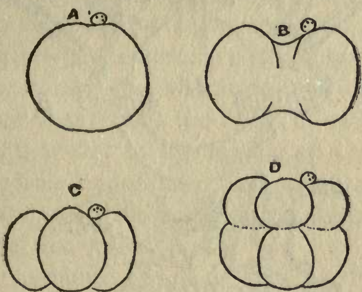


Fig. 35.—Showing the division of an animal egg-cell into like parts (optical images) (*heredity*) and (D) into upper and lower layers, which are unlike (variation).

The two cells (B) or four cells (C), if shaken apart, will each develop into a perfect little fish, but a half and a quarter respectively the size of a fish developed from (A).

The eight cells (D) will not develop into a fish if shaken apart, but will die. A qualitative division has taken place along the horizontal line, cleaving the four cells into eight. That is variation.

But Mendel's discovery went farther than this. Besides a single pair of alternative characters there are in peas and in animals several such pairs of allelomorphs, the colours of the flowers for example, and it was in connection with these that Mendel made his further advance. By

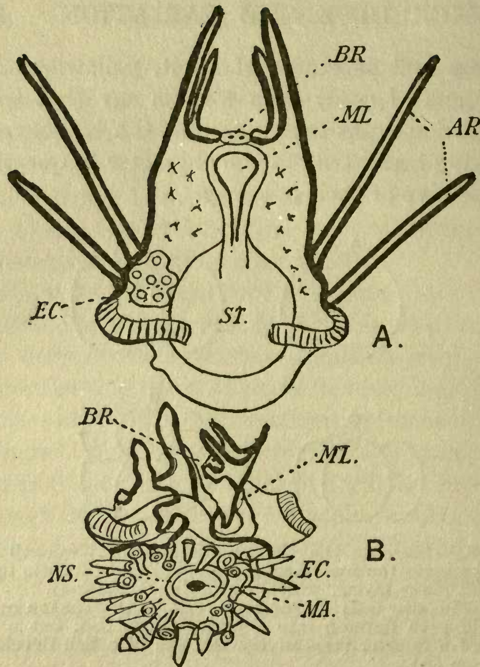


Fig. 36.

THE BIRTH OF A SEA URCHIN: to illustrate the struggle between larval and adult tissues (see p. 214). ($\times$ 45.)

A. The free-swimming larva called *Pluteus*, from its resemblance to a painter's easel (inverted). The body is drawn out into ciliated arms (AR), and is provided with a larval mouth (ML), a food-tube (ST), and a brain with two eye-spots (BR). On the left side of the larva is the first trace of the future *Echinus* (EC).

B. The struggle showing the *Echinus* victorious over the larva. The latter has now shrunk, and the *Echinus* has developed at its expense. MA, mouth of the *Echinus*. NS, nervous system of the *Echinus*. Spines and suckers are developing on the body of the latter. (After MacBride, slightly modified.)

crossing tall purple peas with short white ones, the crossed individuals gave rise, in the second generation, to short purple and tall white peas as well as to the original forms. That is to say, Mendel found that a definite proportion of *new* pure combination are produced. Thus organic characters of this type appear as "factors which can be replaced by alternative characters without otherwise altering the constitution of the organism" (Doncaster): and the result of such knowledge is seen to-day in the raising of a new form of wheat, which combines the valuable quality of a delicate race with the resisting power against disease of a less valuable one.

Now in animals the discovery of "factors," or alternative characters, which behave in this way has made much progress. Recombinations can be made in animals as in the case of the sweet pea. Thus in the guinea-pig, starting from an albino, smooth coat, long hair, and crossing with a coloured, rough-coated, short-haired specimen, the first generation is coloured, with rough coat and short hair. These crossed together give various recombinations such as albino, rough coat, short hair; coloured, smooth coat, long hair. By selecting these any combination can be fixed, and after experience has been gained the operation may be guided with certainty.

Natural inheritance is, however, far more com-

plex than this, and the knowledge of how pairs of characters may react upon one another so as to give a combined effect—so far studied chiefly in the colours of animals—is sufficient to lead to the conclusion that the general appearance of an animal is no guide to its real constitution, but that this constitution can in many cases be determined by principles which are only now becoming fully appreciated.

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GLOSSARY—INDEX